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STABL USER MANUAL

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PURDUE UNIVERSITY



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TO: J. F. McLaughlin, Director
Joint Highway Research Project

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

June 4, 1975

Project: C-36-36K

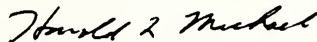
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The attached "STABL USER MANUAL" is a user manual for the computer program named STABL which was developed during the research reported in the Final Report titled "Computer Analysis of General Slope Stability Problems", JHRP-75-8, June 1975.

A listing of the Computer Program STABL is available on written request to the Joint Highway Research Project, Civil Engineering Building, Purdue University, West Lafayette, Indiana 47907 at the cost of reproduction (98 pages). The program in card deck form or on tape can also be furnished at cost. Details should be requested.

This Manual together with the Final Report completes the activity on this research project. The Manual is submitted for acceptance as fulfillment of the objectives of the Study.


Respectfully submitted,



Harold L. Michael
Associate Director

HLM:mf

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STABL USER MANUAL

A Description of the Use of STABL's Programmed Solution for
the General Slope Stability Problem

by

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ABSTRACT

This report is a user manual for a computer program named STABL, developed to handle general slope stability problems by an adaptation of the Modified Bishop Method. The adaptation allows for analysis assuming shear surfaces of general shape. The value of the factor of safety obtained by this limiting equilibrium procedure, although not satisfying complete equilibrium, does compare favorably to more accurate methods, which use considerably more computing time and require evaluation of results for reasonableness.

Critical surface searching options include three which generate trial failure surfaces pseudo-randomly of circular shape, of sliding block character, and of general irregular shape. Data are read free-form and checked for compliance with program requirements. Errors are noted, if compliance is not satisfied. The profile and trial failure surfaces are plotted. Problem capabilities include: general profile definition; ground surface surcharge boundary loads; pore pressures approximately defined with respect to a free water surface, defined as a constant through a zone, related proportionally to the overburden, or defined as a combination of the aforementioned; anisotropic strength definition; and pseudo-static earthquake loadings.

INTRODUCTION

STABL is a computer program written in FORTRAN IV source language for the general solution of slope stability problems by a two-dimensional limiting equilibrium method. The calculation of the factor of safety against instability of a slope is performed by a method of slices. The particular method employed in this version of STABL is an adaption of the Modified Bishop method. The adaptation of this method allows the analysis of trial failure surfaces other than those of circular shape.

STABL features unique random techniques for general potential failure surfaces for subsequent determination of the more critical surfaces and their corresponding factors of safety. One technique generates circular surfaces; another, surfaces of sliding block character; and a third, more general irregular surfaces of random shape. The means for defining a specific trial failure surface and analyzing it is also provided.

Complications which STABL is programed to handle include the following: heterogeneous soil systems, anisotropic soil strength properties, excess pore water pressure due to shear, static groundwater and surface water, pseudo-static earthquake loading, and surcharge boundary loading.

Plotted output is provided as a visual aid to confirm whether the problem input data are correct. STABL-generated error messages

pinpoint locations where input data are inconsistent with STABL's input requirements. STABL's free-form data input eases the task of preparing data cards with a keypunch machine or typing lines of data with a teletype terminal, resulting in a reduction of input errors.

This Manual is not intended to explain how STABL functions or what assumptions are made to arrive at a solution. However, it has sometimes been found useful to do so when explanations of the use of certain features of STABL are presented. For a more detailed explanation of the logical operation of STABL and mathematical models employed refer to the JHRP Report by the author, "Computer Analysis of General Slope Stability Problems", JHRP-75-8, June 1975.

PROBLEM GEOMETRY

To start off, it is necessary to plot the problem's geometry to scale on a rectangular coordinate grid. Coordinate axes should be chosen carefully such that the total problem is defined within the first quadrant. This enables the graphical aspects of the program to function properly. In doing this, potential failure surfaces which may develop beyond the toe or the crest of the slope should be anticipated (Figure 1). Deep trial failure surfaces passing below the horizontal axis are not allowed, as well as, trial failure surfaces which extend beyond the defined ground surface in either direction. If any coordinate point defining the problem's geometry is detected by the program to lie outside the first quadrant, an appropriate error code is displayed and execution of STABL is later determined.

Graphical output resulting from execution of STABL is scaled to a 5" x 8" plot of the problem's geometry. The origin of the coordinate system referencing the problem geometry is retained as the origin of the plot, and the scale is maximized so that the extreme geometry point or points lie just within the boundaries of the 5" x 8" plot. Therefore, it is advantageous to fit the problem geometry to the coordinate axes with this in mind. Situations where the resulting plotted profile would be too small in scale to be useful for interpretation should be avoided (Figure 2). Figure 1 is an excellent example of well chosen coordinates where there is enough room for possible failure surface

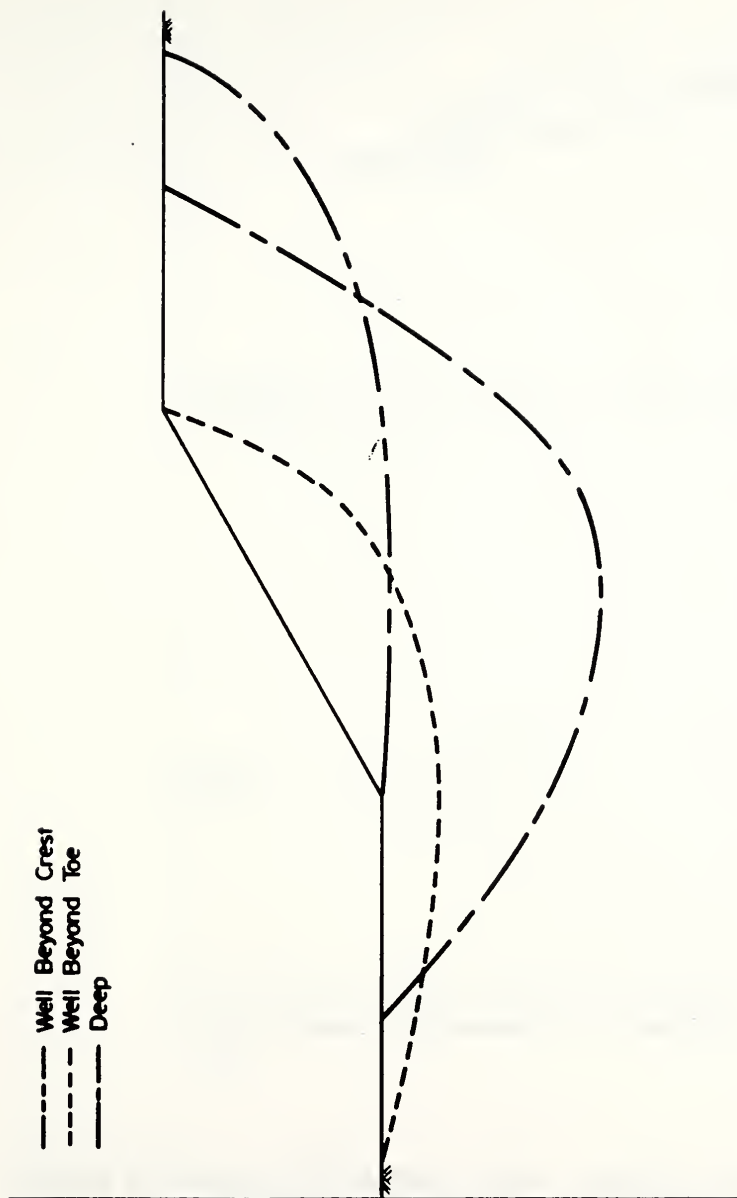
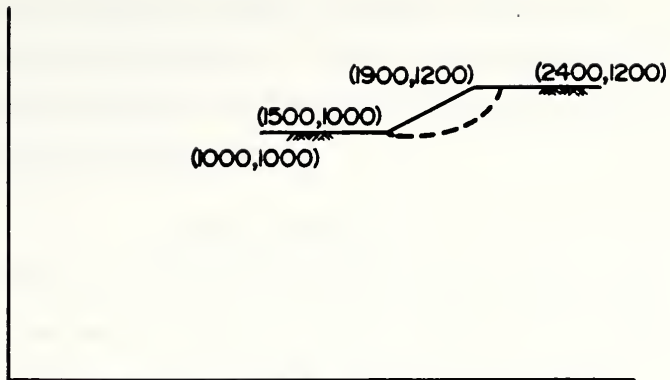
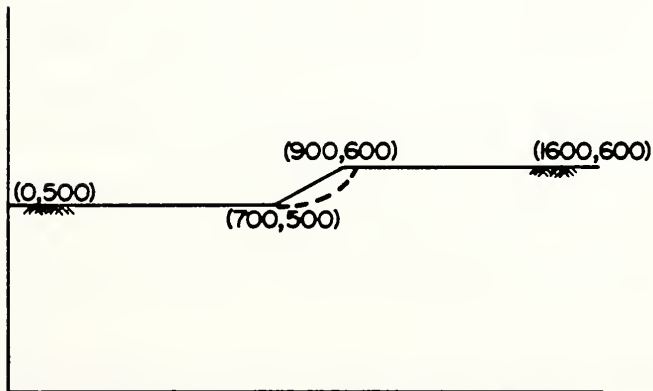


FIGURE 1- EXTENT OF POTENTIAL FAILURE SURFACES.



Coordinates Too Large in Comparison with Height and Length of Slope



Too Much Room Allowed Beyond the Toe and Crest of Slope in Comparison to its Height and Length

FIGURE 2-SCALING RESULTING FROM CORRECT BUT INADEQUATE DEFINITION OF PROBLEM.

development, and the profile geometry is plotted to the largest scale possible within the allowed format. If these requirements are not considered before the input data are prepared, revision of the entire set of data could later become a necessity.

Profile Boundaries

The ground surface and subsurface demarcations between regions of differing soil parameters are approximated by straight line segments. Any configuration can be portrayed so long as the sloping ground surface faces the vertical axis and does not contain an overhang.

Assigned with each surface and subsurface boundary is a soil type which represents a set of soil parameters describing the area projected beneath. Vertical lines, passing through the end points of each boundary, bound the area in lateral extent. The area below a boundary may or may not be bound at its bottom by another boundary beneath which different soil parameters would be defined (Figure 3). Note that vertical boundaries are not required (except at the ground surface), since a vertical line does not project an area beneath it. If vertical boundaries are used, it does not matter what soil type is assigned to it.

The program requires a certain level of order by which boundary data are prepared. The boundaries may be assigned temporary index numbers for ordering by the following procedure. The ground surface boundaries are numbered first, from left to right consecutively, starting with (1). If a vertical line occurs at the ground surface it must be included. All subsurface boundaries are then numbered in any manner as long as no boundary lies below another having a higher

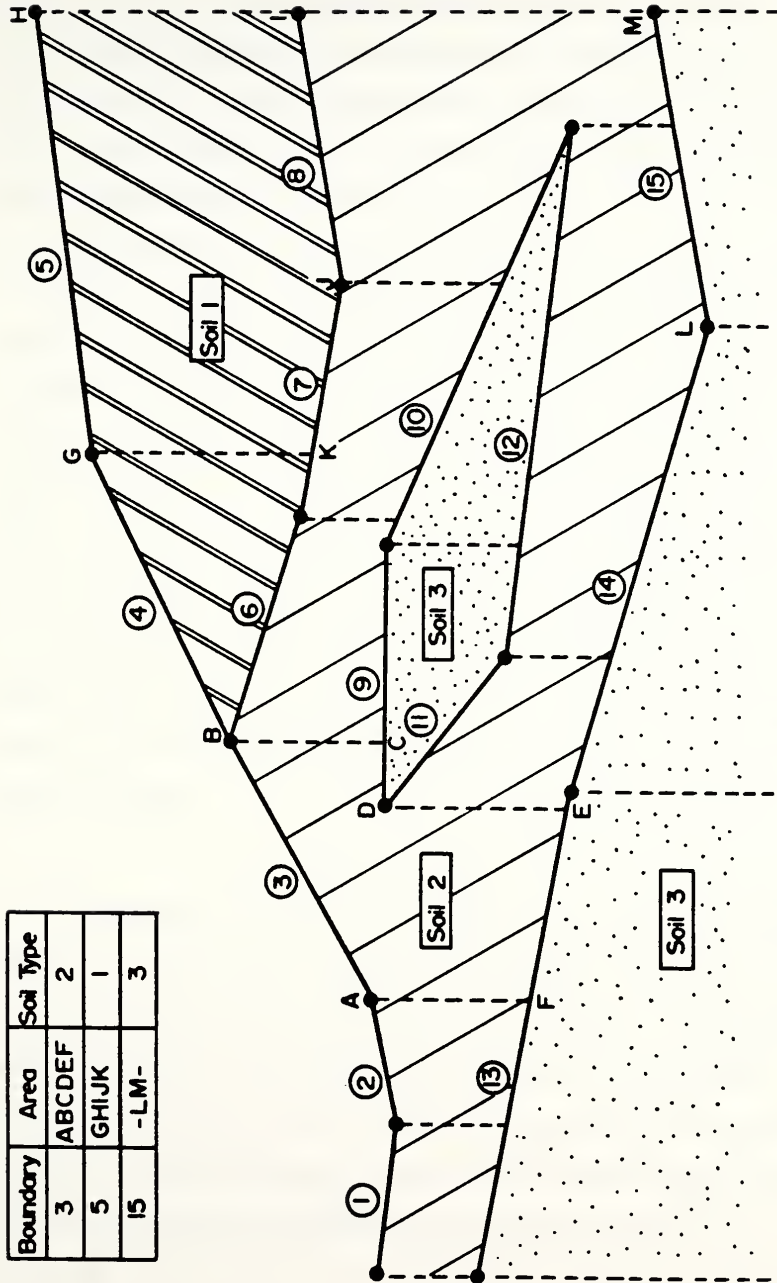


FIGURE 3-RELATIONSHIP OF SOIL TO BOUNDARIES.

number. That is, at any position which a vertical line might be drawn, the temporary index numbers of all boundaries intersecting that line must increase in numerical order from the ground surface downward. After all the boundaries have been temporarily indexed, the data for each boundary should be prepared in that order.

The data set describing a profile boundary line segment consists of X and Y coordinates of the left and right end points and a soil type number indicating the soil type beneath. The end points of each boundary are specified with the left point proceeding the right, and with the X coordinate of each point required to precede its complementary Y coordinate. If a boundary is vertical, it does not matter which end point is specified first, except if it is a ground surface boundary. For this case if the ground surface is to remain continuous, as is required, the coordinates of the left end point of the vertical ground surface boundary should be those of the right end point of the connecting ground surface boundary immediately to the left of the vertical boundary.

Water Surface

If the problem contains a water surface which would intersect a potential failure surface, it can be approximated by a series of coordinate points connected by straight line segments. If used, the water surface must be defined continuously across the horizontal extent of the region to be investigated for possible failure surfaces. It is wise to extend the water surface as far in each lateral direction as the ground surface is defined, to insure meeting this last

requirement (Figure 4). Data for the coordinate points must be ordered progressing from left to right. Each point on the water surface is defined by a X and Y coordinate specified in that order.

The connecting line segments defining the water surface may lie above the ground surface and also may lie coincident with the ground surface or any profile boundary. This enables expression of not only the ground water table but also surfaces of seepage and still water surfaces of bodies of water such as lakes and streams.

The pore pressure at any point below the water surface is calculated using as the pressure head, the vertical distance from the point in question to the water surface. Where a gradient exists, this assumption is generally conservative. However, within the region of a surface of seepage, the assumption is unconservative. Artesian pressures found in heterogeneous soil systems will further complicate the validity of the assumption. Since the error may be large for some flow regimes, other methods for handling the pore water pressures may be more appropriate and are described later. When the water surface is above the ground surface, hydrostatic pressures are assumed to act upon the ground surface.

Individual Failure Surface

If the failure of a slope is being studied and the location of the actual failure surface is known, STABL offers the option of specifying the known surface as an individual surface for analysis. Another situation for which this option would be useful is when the geologic pattern and shear strength data indicate one or more well defined weak paths where a failure surface or surfaces would be expected to occur.

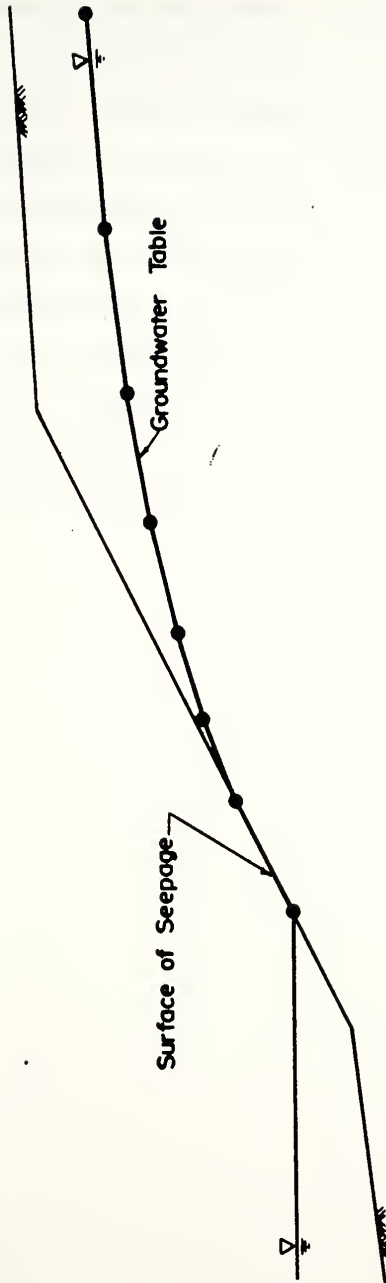


FIGURE 4--WATER SURFACE DEFINED ACROSS ENTIRE EXTENT OF DEFINED PROBLEM.

An individual failure surface is approximated by straight line segments defined by a series of points. The end points of the specified trial failure surface are checked for proper location within the horizontal extent of the defined ground surface. The Y coordinates for these two points need not be correctly specified. STABL directs the calculation of the Y coordinate, for each of these two points, from the intersection of a vertical line defined by the specified X coordinate and the ground surface. However, should the trial failure surface begin or terminate at a vertical ground surface boundary, STABL directs the computer to use the specified value for the Y coordinate. Data for the coordinate points must be ordered from left to right.

BOUNDARY LOADS

Uniformly distributed boundary loads applied to the ground surface are specified by defining their extent, intensity, and direction of application (Figure 5). The limiting equilibrium model used for analysis treats the boundary loads as strip loads of infinite length. The major axis of each strip load is normal to the two-dimensional X-Y plane within which the geometry of slope stability problems is solved. Therefore the extent of a boundary load is its width in the two-dimensional plane.

Data for each boundary load consist of the left and right X coordinates which define the horizontal extent of load application, the intensity of the loading, and its inclination. The intensity specified should be in terms of the load acting on a horizontal projection of the ground surface rather than the true length of the ground surface. Inclination is specified positive counterclockwise from the vertical. The boundaries must be ordered from left to right and are not allowed to overlap.

A boundary load whose intensity varies with position can be approximated by substituting a group of statically equivalent uniformly distributed loads which abut one another. The sum of the widths of the substitute loads should equal the width of the load being approximated. The inclinations should be equivalent, and the intensities of substitute loads should vary as does the load being approximated.

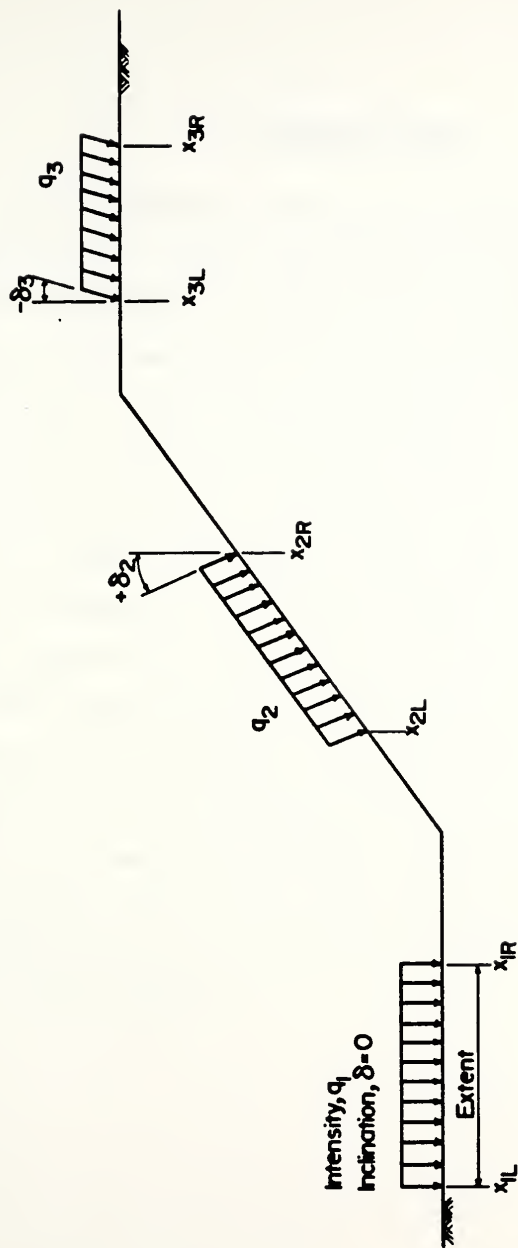


FIGURE 5 DEFINITION OF SURCHARGE BOUNDARY LOADS.

EARTHQUAKE LOADING

The use of earthquake coefficients allows for a pseudo-static representation of earthquake effects within the limiting equilibrium model. A direct relationship is assumed to exist between the pseudo-static earthquake force acting on the sliding mass and the weight of the sliding mass. Specified horizontal and vertical coefficients are used to scale the horizontal and vertical components of the earthquake force relative to the weight of the sliding mass. Positive horizontal and vertical earthquake coefficients indicate that the horizontal and vertical components of the earthquake force are directed leftward and upward, respectively. Negative coefficients are allowed.

STABL considers reductions and increases of pore pressures due to application of the earthquake loading. Earthquake loadings are assumed to occur under undrained conditions. Pore pressures are allowed to go negative for saturated soil, but are not allowed to exceed the cavitation pressure which is specified. Soils which have pore pressures defined other than by location beneath the water surface, are also considered saturated.

SOIL PARAMETERS

Each soil type is described by the following set of isotropic parameters: the moist unit weight, the saturated unit weight, Mohr-Coulomb strength intercept, the Mohr-Coulomb strength angle, a pore pressure parameter, and a pore pressure constant.

The moist unit weight and the saturated unit weight are total unit weights, and both are specified to enable STABL to handle zones divided by a water surface. In the case of a soil zone totally above the water surface, the saturated unit weight will not be used, however, some value must be used for input regardless. Any value including zero will do. Similarly for the case where a soil zone is totally submerged, the moist unit weight will not be used. Again some value must be used for input.

Either an effective stress analysis (ϕ' , c') or total stress analysis (c , $\phi = 0$) may be performed by using the appropriate values for the Mohr-Coulomb strength parameters.

Excess pore water pressure due to shear can be assumed to be related to the overburden by the single parameter r_u . The overburden does not include surcharge boundary loads. The pore pressure constant u_c of a soil type defines a constant pore pressure for any point within the soil described. Either or both of these two options for specifying pore pressures may be used, in combination with pore pressure related to a specified water surface, to describe the pore pressure regime.

Anisotropic Soil

Soil types exhibiting anisotropic strength properties are described by assigning Mohr-Coulomb strength parameters to discrete ranges of direction. The strength parameters would vary from one discrete direction range to another.

The orientation of all line segments defining any potential failure surface can be referenced with respect to their inclination entirely within a range of direction between -90° and $+90^{\circ}$ with respect to horizontal. Therefore the selection of discrete ranges of direction is confined to these limits. The entire range of potential orientation must be assigned strength values.

Each direction range of an anisotropic soil type is established by specifying the maximum inclination α_1 of the range (Figure 6). The data consist of this inclination limit and the Mohr-Coulomb strength angle and strength intercept for each discrete range. Data for each discrete range are required to be prepared progressing in counterclockwise order. The process is repeated for each soil type with anisotropic strength behavior.

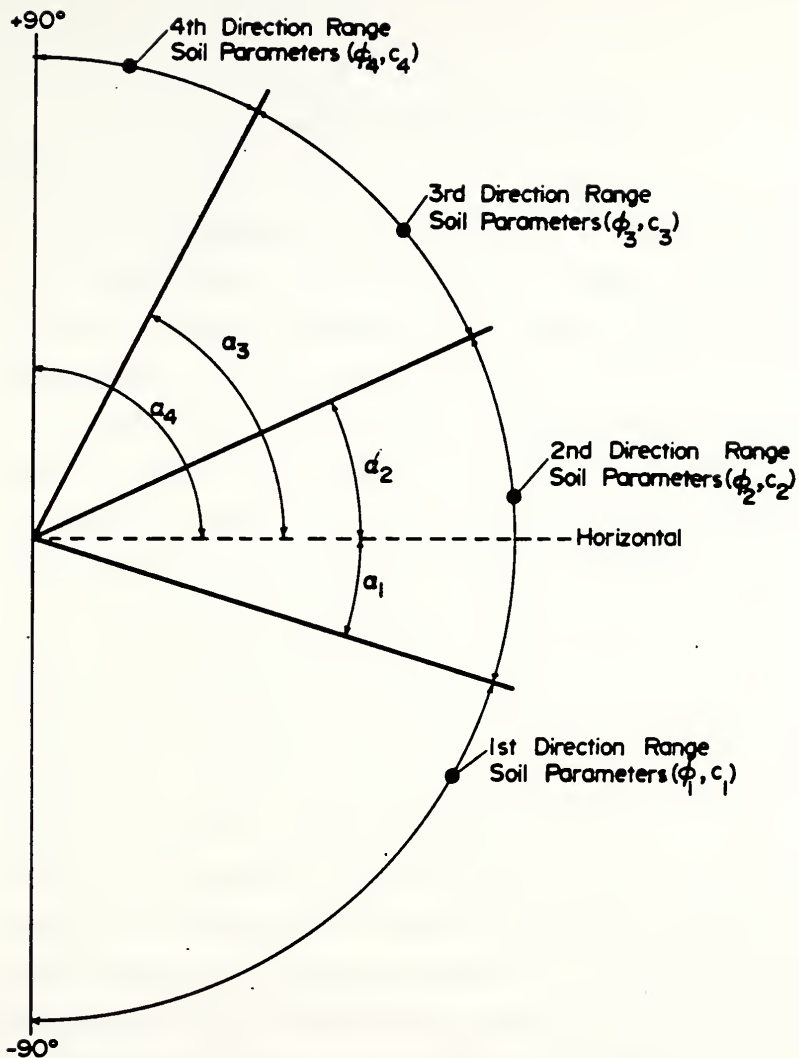


FIGURE 6- STRENGTH ASSIGNMENT TO FOUR DISCRETE DIRECTION RANGES FOR A SINGLE ANISOTROPIC SOIL TYPE.

CONCEPT OF SEARCHING ROUTINES

STABL can generate any specified number of trial failure surfaces in a random fashion. The only limitation is computation time and cost. Usually 100 surfaces is adequate. Each surface must meet specified requirements. As each acceptable surface is generated, the corresponding factor of safety is calculated. The ten most critical are accumulated and sorted by the values of their factors of safety. After all the specified number of surfaces are successfully generated and analyzed, the ten most critical surfaces are plotted so the pattern may be studied.

If the pattern is compact such that the ten most critical surfaces form a thin zone, and if the range in the value of the factor of safety for these ten surfaces is small, an additional refined search would be unnecessary. However, if just the opposite is true, an additional search with stricter surface requirements would then be necessary. There are two exceptions to this last case. The first is when one, some, or all of the ten most critical surfaces have a factor of safety below a value of 1, or perhaps a criterion the user has established. The second is when the most critical surface has a very large value for the factor of safety, much greater than the criterion for acceptance, and it is obvious that further refinement of a search for a more critical surface will not produce a value of the factor of safety less than the established criterion.

Circular and Irregular Surfaces

The searching routines which generate circular and irregular shaped trial failure surfaces are basically similar in use, and are therefore discussed together.

Trial failure surfaces are generated from the left to the right. Each surface is composed of a series of straight line segments of equal length, except for the last segment which most likely will be shorter. The length used for the line segments is specified.

Generation of an individual trial failure surface begins at an initiation point on the ground surface. The direction, to which the first line segment defining the trial failure surface will extend, is chosen randomly between two direction limits. An angle of 5° less than the inclination of the ground surface to the right of the initiation point would be one limit, while an angle of 45° below the horizontal would be another limit (Figure 7). The first line segment can fall anywhere between these two limits, but the random technique of choosing its position is biased so that it will lie closer to the 45° limit more often than the other.

By specifying zero values for both of the direction limits, the direction limits as described above are automatic. However, the counterclockwise and clockwise direction limits, instead of being calculated under STABL's direction, may be specified. After a preliminary search for the critical surface, it is usually found that all or most of the ten most critical surfaces have about the same angle of inclination for the initial line segments. By restricting the initial line

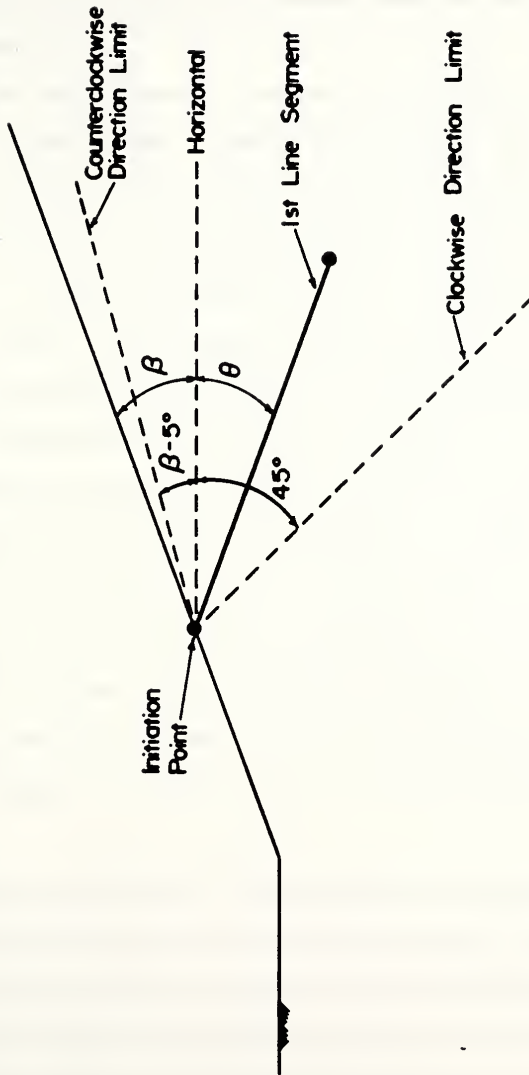


FIGURE 7-GENERATION OF FIRST LINE SEGMENT.

segment within direction limits having a directional range smaller than that which would be used automatically by STABL, and at inclinations which would bracket the initial line segments of surfaces previously determined to be critical, subsequent searches can be conducted more efficiently.

After establishment of the first line segment, a circular shaped trial failure surface is generated by changing the direction of each succeeding line segment by some constant angle (Figure 8) until an intersection of the trial failure surface with the ground surface occurs. In effect, the chords of a circle are generated rather than the circle itself. The constant angle of deflection is obtained randomly.

An irregular shaped surface is generated somewhat differently after establishment of the first line segment. The direction of each succeeding line segment is chosen randomly and independently of the directions of the preceding line segments. Surfaces with reverse curvature are likely, and if a very short length is used for the line segments, a significant amount of kinkiness in the surfaces will be inevitable. Some reverse curvature is desirable but extreme kinkiness is not. To avoid the second case the length of the line segment selected should in general not be shorter than $1/4$ the height of the slope.

When using either of these generation techniques to search for a critical failure surface, the following scheme is employed. STABL directs computation of a specified number of initiation points along the ground surface. The initiation points are equally spaced horizontally between two specified points, which are the leftmost and

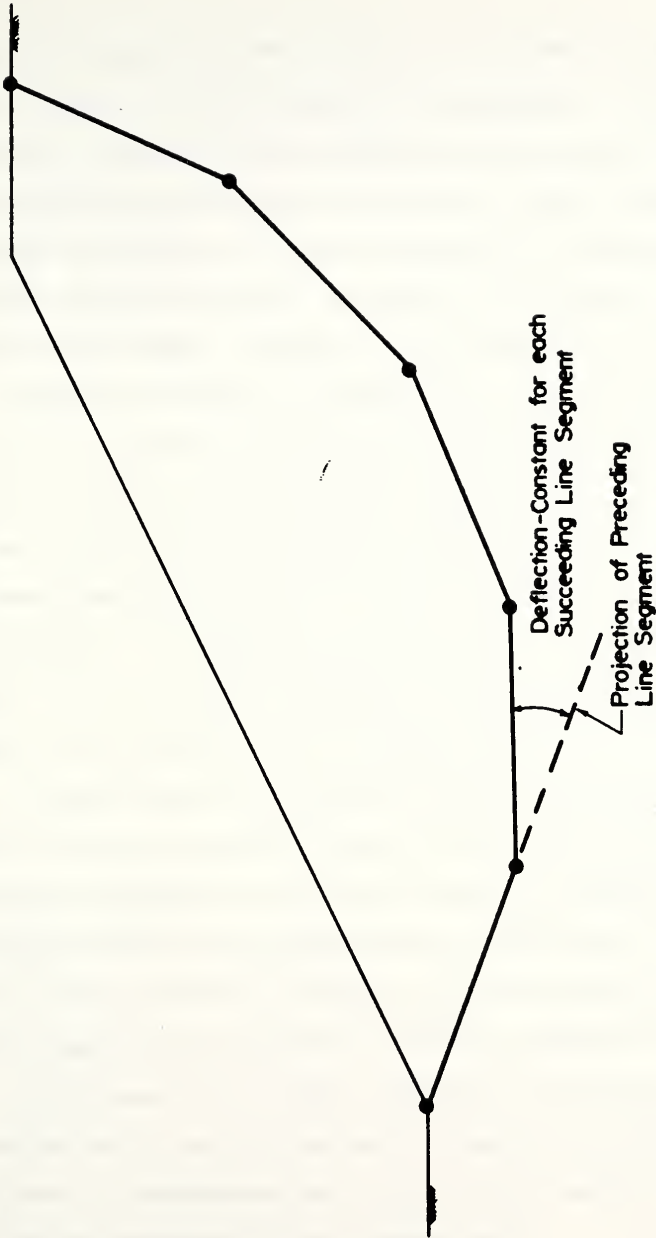


FIGURE 8 - CIRCULAR SURFACE GENERATION.

rightmost initiation points. Only the X coordinates of these two points, specified in left-right order, are required. From each initiation point, a specified number of trial failure surfaces are generated. If the left point coincides with the right, a single initiation point results, from which all surfaces are generated. The total number of surfaces generated will equal the product of the number of initiation points and the number of surfaces generated from each.

Termination limits are specified to minimize the chance of proceeding with a calculation of the factor of safety for an unlikely failure surface. If a generated trial failure surface terminates at the ground surface short of the left termination limit (Figure 9), the surface is rejected prior to calculation of a factor of safety and a replacement is generated. If a generating surface goes beyond the right termination limit, it will be rejected requiring a replacement. The termination limits are also specified in left-right order.

A depth limitation is imposed by specifying an elevation below which no surface is allowed to extend. This is used, for example, to eliminate calculation of the factor of safety for generated surfaces that would extend into a strong horizontal bedrock layer. When a shallow failure surface is expected, the use of the depth limitation prevents generation and analysis of deep trial failure surfaces.

An additional type of search limitation may be imposed to handle situations such as variable elevation of bedrock or delimitating a weak zone and confining the search for a critical surface to that area. This type of limitation will be discussed later.

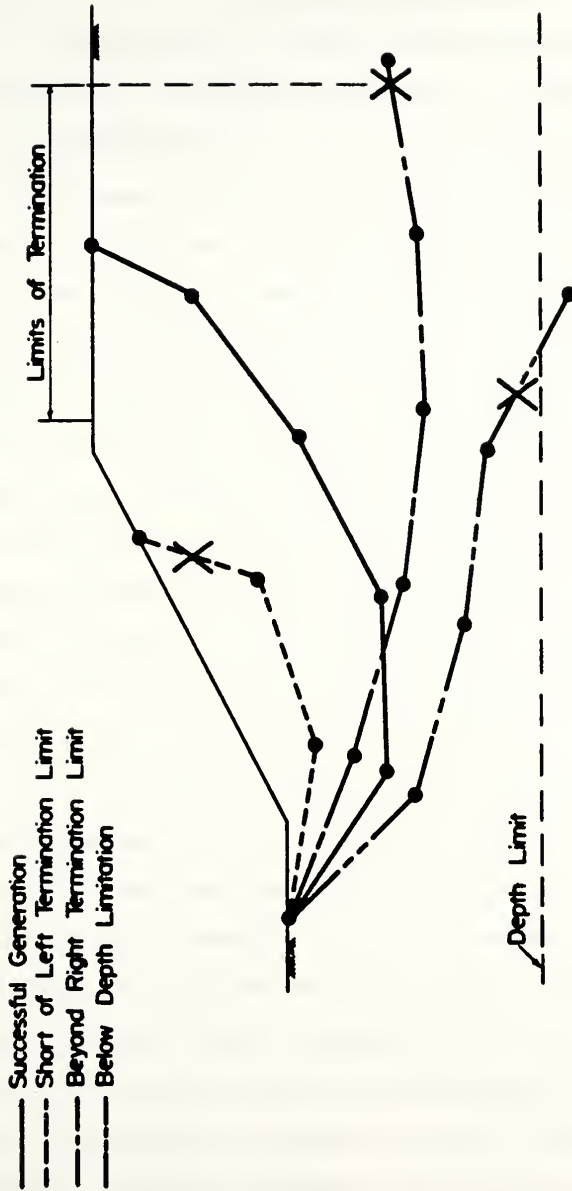


FIGURE 9-TRIAL FAILURE SURFACE ACCEPTANCE CRITERIA.

Sliding Block Surface

A sliding block trial failure surface generator provides a means through which a concentrated search for the critical failure surface may be performed within a well defined weak zone of a soil profile.

In a simple problem involving a sliding block shaped failure surface (Figure 10), the following procedure is used. Two boxes are established within the weak layer with the intent that from within each, a point will be chosen randomly. The two points once chosen define a line segment which is then used as the base of the central block of the sliding mass. Any point within each box has equal likelihood of being chosen. Therefore, a random orientation, position and width of the central block is obtained. The boxes are required to be parallelograms with vertical sides. The top and bottom of a box may have any common inclination. Each box is specified by the length of its vertical sides and two coordinate points which define the intersections of its centerline with its vertical sides (Figure 11).

After the base of the central block is created, the active and passive portions of the trial failure surface are generated using line segments of equal specified length by techniques similar to those used by the circle and irregular trial failure surface generators.

Starting at the left end of the central block's base, a line segment of specified length is randomly directed between the limits of 0° and 45° with respect to the horizontal (Figure 12). The chosen direction is biased towards selection of an angle closer to 45° . This process is repeated as necessary until intersection of a line segment with the ground surface occurs.

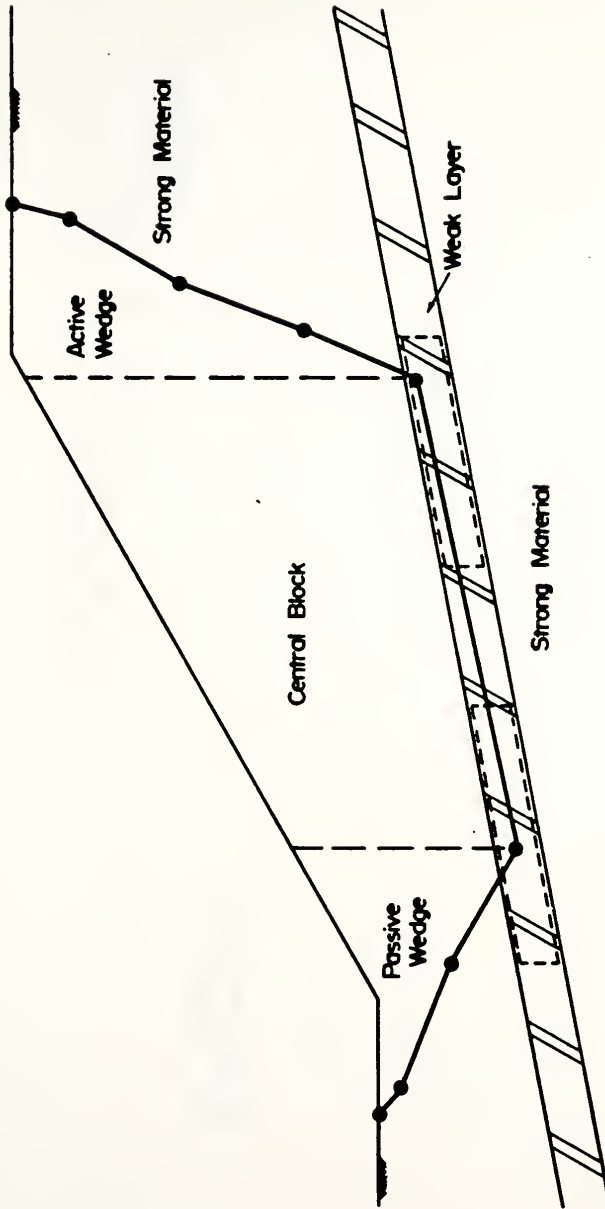


FIGURE 10- SIMPLE SLIDING BLOCK PROBLEM.

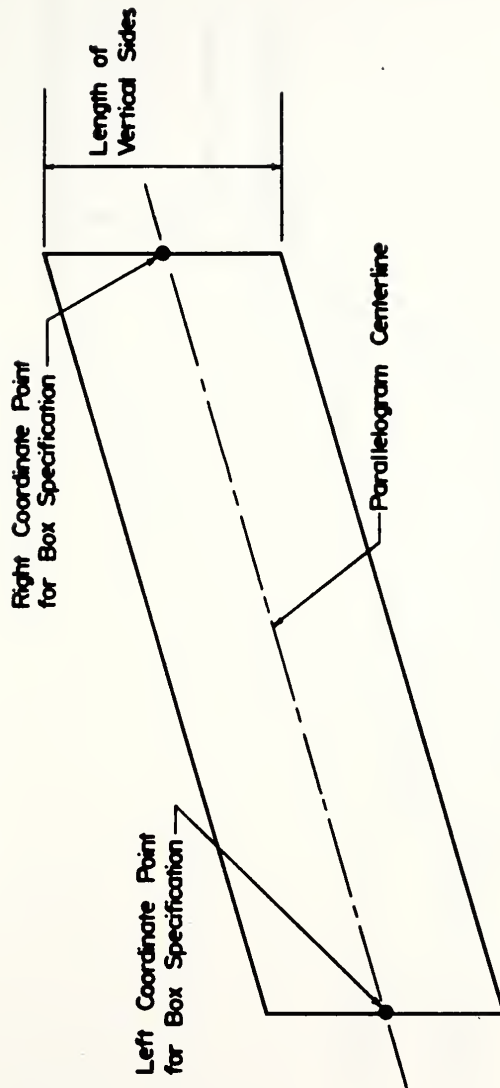


FIGURE 11- SLIDING BLOCK BOX SPECIFICATION.

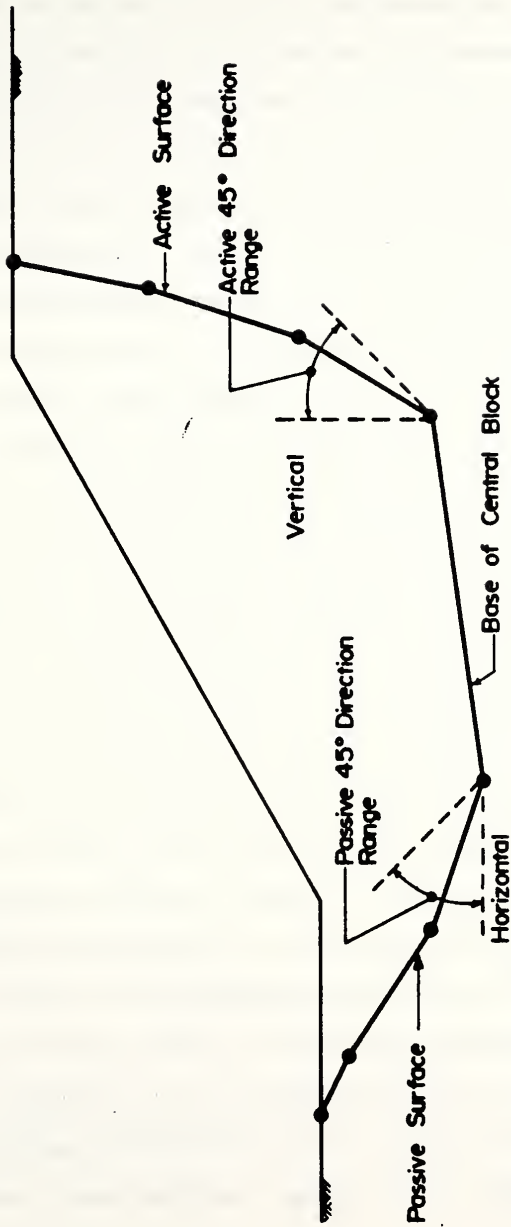
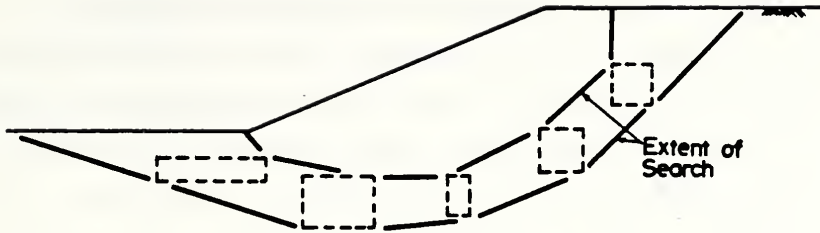


FIGURE 12-GENERATION OF ACTIVE AND PASSIVE SLIDING SURFACES.

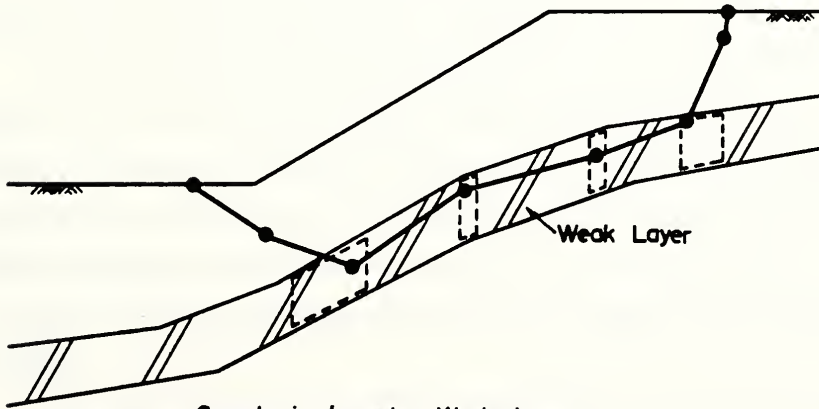
For the passive portion of the trial failure surface, a similar process is used with the limits for selection of the random direction being 0° and 45° with respect to the vertical (Figure 12). The chosen direction is biased towards selection of an angle nearer 45° .

Program STABL allows the use of more than two boxes for the formation of the central block (Figure 13). The search may be limited to a irregularly shaped weak zone this way. Another application might be to conduct a search within a zone previously defined as being critical by use of the analysis command RANDOM.

Degenerate cases of parallelogram boxes are permitted. For example, if both points specified as the intersections of a parallelogram's centerline with its vertical sides are identical, and the length of the parallelogram's vertical sides is non-zero, then a vertical line segment, in effect, is defined. When a trial failure surface is generated, each point along the vertical line segment's length has an equal likelihood of becoming a point defining the surface. The vertical line segment could further degenerate into a point if a zero value is specified for the length of the parallelogram's vertical sides. Then all surfaces generated would pass through the single point. One more case of a degenerate parallelogram is a line segment whose inclination and position is that of the parallelogram's centerline. For this case, the length of the vertical sides is zero but the intersections of the parallelogram's centerline with its vertical sides are not identical. Again, any point along the length of the line segment has equal likelihood of becoming a point defining a generated trial failure surface.



Intensive Search of Critical Zone Previously
Defined by CIRCLE or RANDOM



Search in Irregular Weak Layer

FIGURE 13- SLIDING BLOCK GENERATOR USING MORE
THAN TWO BOXES.

Surface Generation Boundaries

As an additional criterion for acceptance of generating trial failure surfaces, an ability to establish boundaries through which a surface may not pass has been provided. Such boundaries may be used with any surface generating routine. Each generation boundary specified is defined by two coordinate points. If a generating surface intersects the line segment defined by the pair of coordinate points, it will either be rejected and a replacement surface will be generated, or the surface will be deflected so that it may be successfully completed. The amount of deflection permitted for a trial failure surface is limited, and when it is insufficient to clear the surface generation boundary intersected, the surface is rejected.

When specifying surface generation boundaries the coordinate points of the left end point should precede those of the right end point. For the case of vertical boundaries, the order is not important. Along with the total number of boundaries, the number of them which deflect generating surfaces upward is specified. The data for these boundaries are required to precede the data for boundaries that deflect downward.

As mentioned previously, a variable elevation bedrock surface can be bounded so that no generated surfaces will pass through the rock. For this case, all the surface generation boundaries defining the bedrock surface would be specified to deflect intersecting trial failure surfaces upward. Another use might occur after a critical zone has been roughly defined by a searching technique. This zone could be

bound so that the subsequent search will be completely confined to it. Surface generation boundaries above the zone would be specified to deflect downward, and those below the zone, upward.

An important consideration that should be given whenever any type of limitation is imposed for conducting a search for a critical surface is how many generating surfaces are likely to be rejected. A rejected surface is lost effort regardless of how efficiently it was generated by STABL. Perhaps for example, a multiple box search using command BLOCK would be more efficient than using RANDOM with strict limitations.

DATA PREPARATION

A primary goal during the development of program STABL, was to maintain a simple format for data preparation and input. This was felt to be very important because much time can be consumed getting the "bugs" out of the input data, especially by a new or occasional user.

In an attempt to reduce preparation errors and debugging time, STABL has four helpful features: (1) problem orientated language; (2) free-form data input; (3) execution time data consistency checking; and (4) graphical display of input and output geometry data. These features will be discussed in following sections.

Problem Orientated Language

This feature allows the selection, by command, of only those portions of STABL which are required to solve a particular problem. It also provides flexibility in problem modification for additional analyses during a single execution of STABL.

Below are listed the commands understood by STABL and their primary functions. There are essentially two types; data commands and analysis commands.

Data Commands:

PROFIL - initiate problem; read and store boundary data defining ground surface and subsurface material interfaces.

SOIL - read, check, and store isotropic soil parameter data.

Data Commands (continued):

- ANISO - read, check, and store anisotropic strength parameter data.
- WATER - read, check, and store data defining a water surface.
- SURFAC - read, check, and store data defining a single trial failure surface.
- LOADS - read, check, and store data defining surface boundary surcharge loads.
- EQUAKE - read and store pseud-static earthquake coefficients and cavitation pressure.
- LIMITS - read, check, and store data defining surface generation boundaries.

Analysis Commands:

- EXECUT - calculate factor of safety for single specified trial failure surface.
- CIRCLE - generate circular surfaces and determine critical surfaces.
- RANDOM - generate irregular surfaces and determine critical surfaces.
- BLOCK - generate sliding block surfaces and determine critical surfaces.

The data commands' primary functions are to read data pertinent to the definition of a particular slope stability problem, to check the data for consistency with program requirements, and to store these data for subsequent use by the analysis commands.

The analysis commands' primary purpose is analysis of the problem in some manner using previously stored data. One such way is the analysis of a single trial failure surface previously defined by the data command SURFAC. Another way is to generate potential failure surfaces, searching for the critical surfaces, using one or more of the surface generation techniques.

General Rules for Use of Commands

All commands may be used as often as desired, however, there are some restrictions that are imposed regarding sequencing them for execution.

Once a data command is invoked, the data, stored as a result, remain in effect until replacement or suppression is effected by another usage of the same command. There are two exceptions to this. The first concerns the use of command PROFIL. The command prepares STABL for a new problem by defining a new profile. As a result, all data, which may have been stored by previous usages of other data commands in the execution sequence, will be lost. Incidentally, PROFIL is required to be the first command in the execution sequence. The second exception involves use of the analysis commands CIRCLE, BLOCK, and RANDOM. Use of these commands will destroy the trial failure surface data stored by command SURFAC.

Temporary suppression of data previously stored by any of the commands WATER, LOADS, LIMITS, and ANISO is accomplished by a special use of each command. Each of the commands require that the number of repetitive data sets be specified. By specifying zero, STABL is instructed to suppress all data pertinent to the particular command used. While suppressed, the data are not available for use by the analysis commands. The data will remain suppressed until reactivated by a second use of the same command with zero specified. If new data are read and stored while old data are suppressed, the old data are lost for further use.

Isotropic soil parameters may be modified by specifying the number zero and the number of soil types which are to be changed. Then the soil type number and appropriate soil parameters are specified for each soil type modified.

Use of the analysis commands requires, as a minimum, definition of a problem's profile and the soil parameters. In addition, use of the analysis command EXECUT requires definition of a specific trial failure surface.

Below is an example of how some commands might be sequenced.

PROFIL .. data (1)	
SOIL .. data (2)	
SURFAC .. data (3)	
EXECUT	Factor of safety calculation with data (1), (2), and (3).
WATER .. data (4)	
EXECUT	Factor of safety calculation with data (1), (2), (3), and (4).
SURFAC .. data (5)	Replaces data (3) with data (5).
EQUAKE .. data (6)	
EXECUT	Factor of safety calculation with data (1), (2), (4), (5), and (6).
WATER .. suppress data (4)	
EXECUT	Factor of safety calculation with data (1), (2), (5), and (6).
WATER .. reactivate data (4)	
EQUAKE .. data (7)	Replace data (6) with data (7).
EXECUT	Factor of safety calculation with data (1), (2), (4), (5), and (7).

Command Sequence example (continued)

PROFIL .. data (8)	Nullifies all previous data - initiates new problem.
EQUAKE .. data (9)	
SOIL .. data (10)	
SURFAC .. data (11)	
EXECUT	Factor of safety calculation with data (8), (9), (10), and (11).

Free-Form Data Input

A primary goal during the development of STABL, was to simplify its use regardless of its complexity. This was felt to be very important because many unsuccessful attempts to use computer programs are largely due to faulty preparation of data, which is generally the result of confusing program requirements. Another source of abortive attempts are rigid requirements for proper placement of data items within specific format fields, e.g., integers right adjusted.

To ease requirements of data input, a method for reading numbers free-form has been incorporated within STABL. This method is especially useful when typing data with a teletype terminal.

Typing Instructions for Free-Form Data Input

Keypunch (or type) all commands on individual cards (or lines) commencing with the first column. When the computer cannot match your command with one which STABL has been programmed to recognize, your command will be displayed with an error message as output and execution will be terminated. Be certain the spelling of each command is correct.

Each card containing numerical data should be keypunched such that the first data item on a card commences with the first column. One and only one blank space should separate each subsequent data item on a card. STABL directs the computer to read data from the next card when two or more blank spaces are encountered. If a gap of more than one blank space occurs between two adjacent data items, all data items on the card following the gap will not be read. Instead, data on the following card will be read next. If unintentional, a shift in all data subsequently read will occur. Eventually, an indirect error will be generated. Most likely is a situation where a real number is read as an integer or vice versa.

An integer is a whole number generally used for counting, while a real number is a rational number used for measurement of magnitude. STABL requires that an integer contains no decimal point, while a real number must.

For the problem description associated with the data command PROFIL, any combination of alpha-numeric characters, blanks, and special characters may be used within the eighty columns of one card. The description will appear on two lines as printed output of forty columns each, so the description should be written accordingly.

Input for each Command

The data for each command and their organization are outlined below. A new line of data should be started, wherever a data card or command card is encountered.

INPUT FOR PROFILE

COMMAND CARD	PROFIL	Command Code
DATA CARD	Title	
DATA CARD	Integer	Total number of boundaries
	Integer	Number of surface boundaries
DATA CARD	Real	X coordinate of left end of boundary (ft)
	Real	Y coordinate of left end of boundary (ft)
	Real	X coordinate of right end of boundary (ft)
	Real	Y coordinate of right end of boundary (ft)
	Integer	Soil type index number for material immediately beneath boundary

NOTE: Repeat proceeding data card for each boundary.

INPUT FOR SOIL TYPES

COMMAND CARD	SOIL	Command Code
DATA CARD	Integer	Number of soil types
DATA CARD	Real	Moist unit weight (pcf)
	Real	Saturated unit weight (pcf)
	Real	Isotropic strength intercept (psf)
	Real	Isotropic strength angle (deg)
	Real	Pore pressure parameter
	Real	Pore pressure constant (psf)
	* Integer	Piezometric surface number

NOTE: Repeat proceeding data card for each soil type.

INPUT FOR MODIFYING SOIL TYPES

(if specified)

COMMAND CARD	SOIL	Command Code
DATA CARD	Integer	Number zero (0)
	Integer	Number of soil types to be modified
DATA CARD	Integer	Soil type number
	Real	Moist unit weight (pcf)
	Real	Saturated unit weight (pcf)
	Real	Isotropic strength intercept (psf)
	Real	Isotropic strength angle (deg)
	Real	Pore pressure parameter
	Real	Pore pressure constant (psf)
	* Integer	Piezometric surface number

NOTE: Repeat proceeding data card for each soil type modified.

* If no piezometric surface is specified, any number can be used.

INPUT FOR STRENGTH ANISOTROPY

(if specified)

COMMAND CARD	ANISO	Command Code
DATA CARD	Integer	Number of anisotropic soil types
DATA CARD	Integer	Soil type index number
	Integer	Number of directional strength parameter data sets

NOTE: Repeat proceeding data card and the following set of data cards for each anisotropic soil type.

DATA CARD	Real	Counterclockwise direction limit (deg)
	Real	Strength intercept (psf)
	Real	Strength angle (deg)

NOTE: Repeat proceeding data card for each range of direction.

INPUT FOR SUPPRESSING OR REACTIVATING STRENGTH ANISOTROPY

(if specified)

COMMAND CODE	ANISO	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR WATER SURFACE

(if specified)

COMMAND CARD	WATER	Command Code
DATA CARD	Integer	Number of piezometric surfaces defined
	Real	Unitweight of water *

NOTE: Repeat the following set of data cards for each piezometric surface.

DATA CARD	Integer	Number of points defining the water surface
DATA CARD	Real	X coordinate of point on water surface (ft)
	Real	Y coordinate of point on water surface (ft)

NOTE: Repeat proceeding data card for each point on the water surface.

* If 0. is specified, 62.4 (pcf) is assumed.

INPUT FOR SUPPRESSING OR REACTIVATING WATER SURFACE

(if specified)

COMMAND CARD	WATER	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR SPECIFIC FAILURE SURFACE

(if specified)

COMMAND CARD	SURFAC	Command Code
DATA CARD	Integer	Number of points defining the failure surface
DATA CARD	Real	X coordinate of point on failure surface
	Real	Y coordinate of point on failure surface

NOTE: Repeat proceeding data card for each point on the failure surface.

INPUT FOR BOUNDARY LOADS

(if specified)

COMMAND CARD	LOADS	Command Code
DATA CARD	Integer	Number of boundary loads
DATA CARD	Real	X coordinate of left end of boundary load (ft)
	Real	X coordinate of right end of boundary load (ft)
	Real	Intensity of boundary load (psf)
	Real	Angle inclination of boundary load - positive counterclockwise from vertical (deg)

NOTE: Repeat proceeding data card for each boundary load.

INPUT FOR SUPPRESSING OR REACTIVATING BOUNDARY LOADS

(if specified)

COMMAND CARD	LOADS	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR EARTHQUAKE LOAD

(if specified)

COMMAND CARD	EQUAKE	Command Code
DATA CARD	Real	Earthquake coefficient for horizontal acceleration
	Real	Earthquake coefficient for vertical acceleration
	Real	Cavitation pressure (psf)

INPUT FOR ANALYSIS OF SPECIFIED TRIAL SURFACE

(if specified)

COMMAND CARD	EXECUT	Command Code
--------------	--------	--------------

INPUT FOR TRIAL SURFACE GENERATION LIMITS

(if specified)

COMMAND CARD	LIMITS	Command Code
DATA CARD	Integer	Total number of generation boundaries
	Integer	Number of generation boundaries which deflect upward
DATA CARD	Real	X coordinate of left end of generation boundary (ft)
	Real	Y coordinate of left end of generation boundary (ft)
	Real	X coordinate of right end of generation boundary (ft)
	Real	Y coordinate of right end of generation boundary (ft)

NOTE: Repeat proceeding card of each generation boundary.

INPUT FOR SUPPRESSING OR REACTIVATING TRIAL SURFACE GENERATION LIMITS

(if specified)

COMMAND CARD	LIMITS	Command Code
DATA CARD	Integer	Number zero (0)

INPUT FOR CIRCULAR SURFACE SEARCHING

(if specified)

COMMAND CARD	CIRCLE	Command Code
DATA CARD	Integer	Number of initiation points
	Integer	Number of surfaces to be generated from each initiation point
	Real	X coordinate of leftmost initiation point (ft)
	Real	X coordinate of rightmost initiation point (ft)
	Real	X coordinate of left termination limit (ft)
	Real	X coordinate of right termination limit (ft)
	Real	Minimum elevation of surface development (ft)
	Real	Length of segments defining surfaces (ft)
	Real	Counterclockwise direction limit for surface initiation (deg)
	Real	Clockwise direction limit for surface initiation (deg)

LIST FOR IRREGULAR SURFACE SEARCHING

(if specified)

COMMAND CARD	RANDOM	Command Code
DATA CARD	Integer	Number of initiation points
	Integer	Number of surfaces to be generated from each initiation point
	Real	X coordinate of leftmost initiation point (ft)
	Real	X coordinate of rightmost initiation point (ft)
	Real	X coordinate of left termination limit (ft)
	Real	X coordinate of right termination limit (ft)
	Real	Minimum elevation of surface development (ft)
	Real	Length of segments defining surfaces (ft)
	Real	Counterclockwise direction limit for surface initiation (deg)
	Real	Clockwise direction limit for surface initiation (deg)

INPUT FOR BLOCK SURFACE SEARCHING

(if specified)

COMMAND CARD	BLOCK	Command Code
DATA CARD	Integer	Total number of surfaces to be generated
	Integer	Number of boxes used to generate base of central block
	Real	Length of segments defining surfaces (ft)
DATA CARD	Real	X coordinate of left end of centerline defining the box (ft)
	Real	Y coordinate of left end of centerline defining the box (ft)
	Real	X coordinate of right end of centerline defining the box (ft)
	Real	Y coordinate of right end of centerline defining the box (ft)
	Real	Length of vertical side of the box (ft)

NOTE: Repeat proceeding data card for each box.

INPUT FOR BLOCK2 SURFACE SEARCHING *)

(if specified)

COMMAND CARD	BLOCK2	Command Code
--------------	--------	--------------

NOTE: Other data cards same as above.

- *) BLOCK2 is a sliding block surface generator modified from BLOCK, the difference being that BLOCK2 generates active and passive portions of the sliding blocks according to the Rankine theory, where BLOCK generates these more randomly.

GRAPHICAL OUTPUT

STABL has two capacities for plotted output. The first uses plotting devices which produce high resolution plots such as Calcomp plotters or Gould electrostatic printers (Figures 14 and 15). A good representation of the problem geometry is clearly displayed. Its use provides an excellent opportunity to visually check whether data have been prepared properly. (Just because STABL accepts the data, doesn't mean they are correct). No indication is given to show what each particular line segment represents, but if the problem is not extremely complicated, this should not be a handicap for data interpretation.

Due to system operation problems, there is usually a lengthy delay in processing these plots. In order to provide immediate access to basically the same plotted information, the line printer and teletype terminal are used to provide crude low resolution plots utilizing print characters (Figure 16). Only the end points of boundaries and series of points defining surfaces are plotted. Each point is assigned a particular character depending upon what the point defines.

Having the knowledge of the problem's geometry, the user can connect the points to make the plot more recognizable. The resolution is low; characters are spaced ten per inch along the vertical axis and six per inch along the horizontal axis. As a result, more than one point may be scaled within the same plot position. When this occurs,

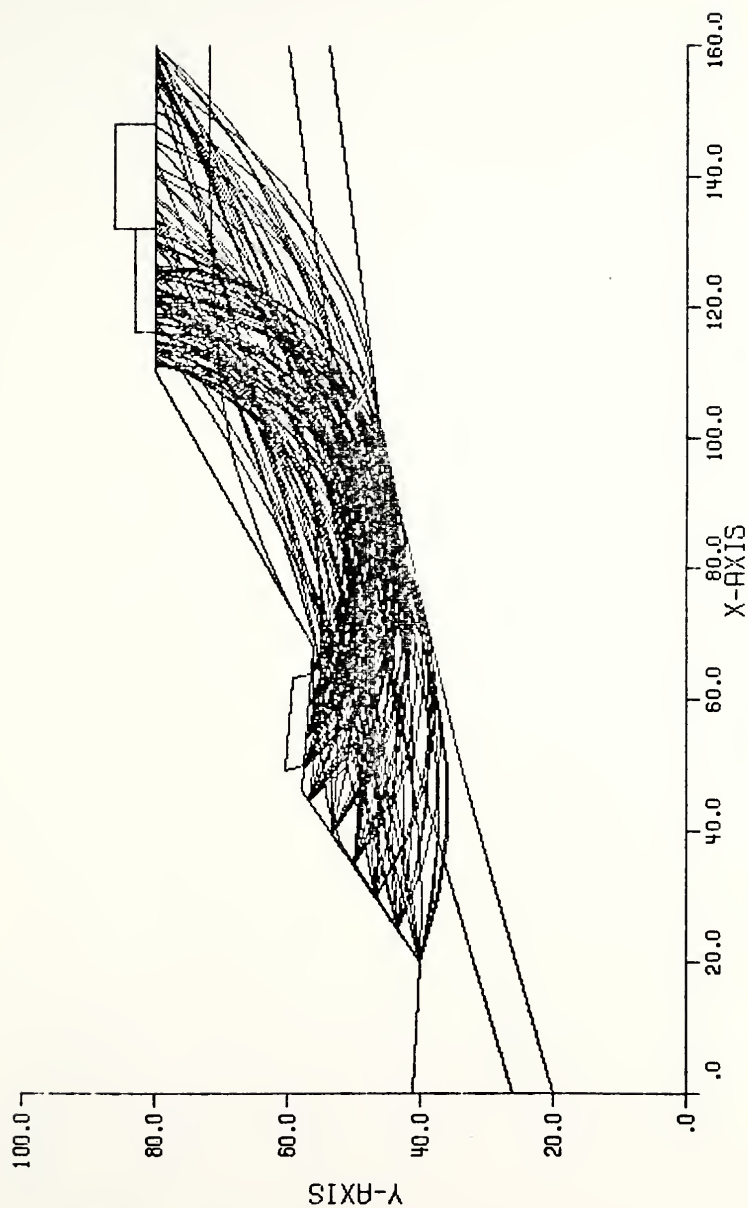


FIGURE 14- EXAMPLE GOULD PLOT WITH 100 CIRCULAR SURFACES.

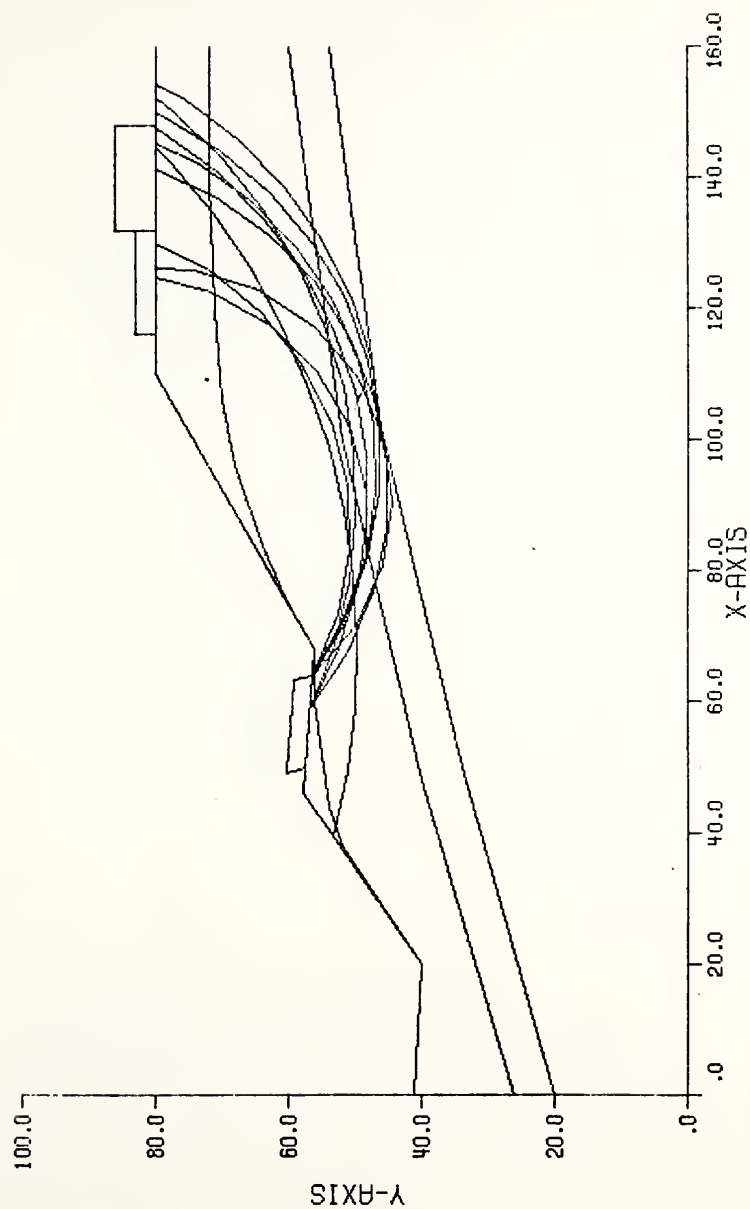


FIGURE 15-TEN MOST CRITICAL SURFACES FROM FIGURE 14.

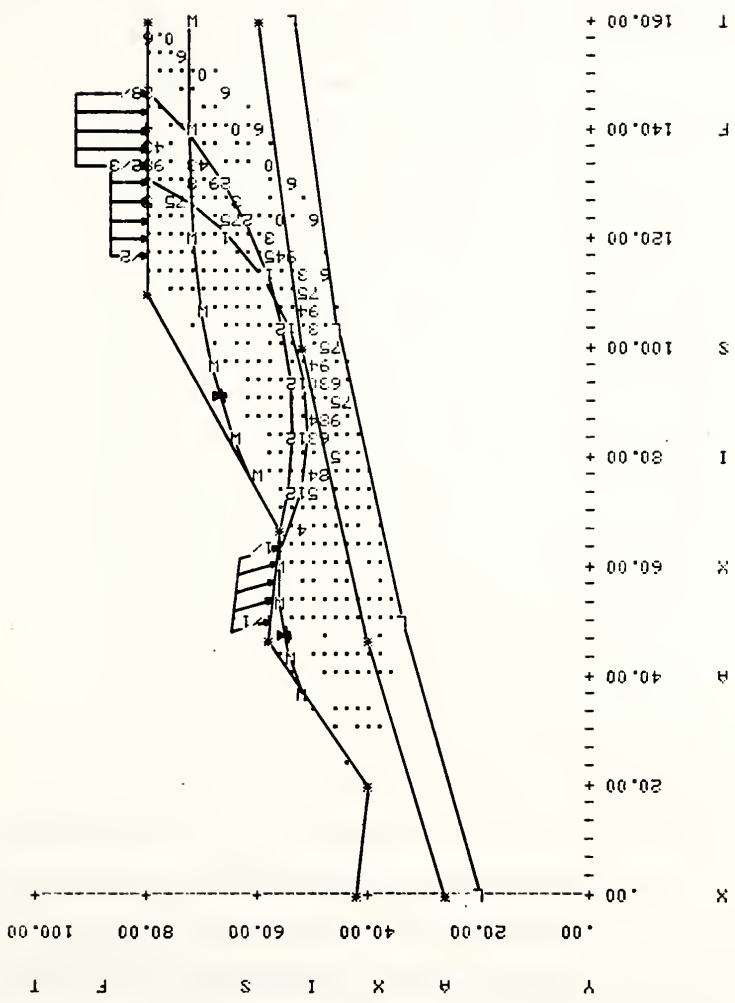


FIGURE 16- EXAMPLE PRINT CHARACTER PLOT.

the point with the highest priority will be represented by its print character. Print characters used by STABL and the points they represent are listed below in order of priority, highest priority first.

- * end points of ground surface and subsurface profile boundaries
- L end points defining surface generation boundaries
- W points defining the water surface
- 1 points defining the most critical generated surface
- 2 points defining the second most critical generated surface
- 3 points defining the third most critical generated surface
- 4 points defining the fourth most critical generated surface
- 5 points defining the fifth most critical generated surface
- 6 points defining the sixth most critical generated surface
- 7 points defining the seventh most critical generated surface
- 8 points defining the eighth most critical generated surface
- 9 points defining the ninth most critical generated surface
- 0 points defining the tenth most critical surface
- . points defining the remaining generated surfaces
- S points defining a specified trial failure surface
- / points defining the location of surcharge boundary loads

The locations of uniformly distributed surcharge boundary loads are represented with a combination of slashes and numerals. Load inclinations are not indicated on print character plots.

The plots are intended to be viewed with the printed output rotated 90° counterclockwise, so the left side of each print character is face down. Viewing a plot at this orientation, the numbers above slashes represent the left ends of a corresponding surcharge boundary

loads. Likewise numbers below slashes represent the right ends of corresponding surcharge boundary loads (Figure 16).

If the extent of a surcharge load is narrow, both the left and right end may appear within the same horizontal print position. The number of that surcharge boundary load then appears both above and below a single slash. Occasionally, when surcharge boundary loads of narrow extent are located adjacent to other loads, some load numbers may be absent.

Printed character plots are also useful for checking input data, although not as conveniently as the first form mentioned. When using surface generation routines, both plots serve well as visual aids for modifying search parameters for subsequent searches.

ERROR MESSAGES

STABL is intended to be error free, assuming that the input data are correctly prepared. To avoid problems when the data have been incorrectly prepared, STABL checks all data, as they are being read in, for consistency with program requirements.

If an inconsistency is found in data submitted, STABL points it out by displaying an error indication. Unless the error is of a nature that demands immediate termination of execution, STABL continues reading data and checking for more errors until a point is reached in execution where termination is required as a consequence of previously determined errors.

The errors are coded and referenced to descriptions in the next section. Each input error has a two digit number prefixed with two letters, associating the error with a particular command or class of errors. The prefixes are listed below.

- SQ - Command Sequence errors
- FR - Free-form Reader errors
- PF - errors associated with command PROFIL
- WA - errors associated with command WATER
- SF - errors associated with command SURFAC
- LM - errors associated with command LIMITS
- LD - errors associated with command LOADS
- SL - errors associated with command SOIL
- AI - errors associated with command ANISO
- RC - errors associated with commands RANDOM and CIRCLE
- BK - errors associated with command BLOCK

Command Sequence Errors

- SQ01 - A command other than PROFIL has been used as the first command in the execution sequence. The first command must be PROFIL. PROFIL initializes STABL prior to reading all data pertinent to the definition of a problem. All data that would have been read prior to encountering the first use of command PROFIL would have been nullified and would not have been made available to STABL for the purpose of analyzing the first problem.

- SQ02 - An attempt to compute the factor of safety of a specified trial failure surface with command EXECUT has been aborted. The isotropic soil parameters describing the soil types of the current problem do not exist. After each use of command PROFIL in an execution sequence, the isotropic soil parameters of each soil type must be specified by use of command SOIL before command EXECUT may be used. Each time a new problem is introduced in an execution sequence by command PROFIL, the soil parameters describing soil types of preceding problems are no longer available for use.

- SQ03 - An attempt to compute the factor of safety of an unspecified trial failure surface with command EXECUT has been aborted. After each use of command PROFIL, CIRCLE, RANDOM or BLOCK, a trial failure surface must be specified with command SURFACE before command EXECUT may be used.

- SQ04 - The command ANISO has been used without the isotropic soil parameters being defined. Anisotropic strength data may not be specified unless the isotropic parameters have been defined by command SOIL after the last use of command PROFIL.

- SQ05 - An attempt to use one of the commands, RANDOM, CIRCLE, or BLOCK has been aborted. The isotropic soil parameters describing the soil types of the current problem do not exist. After each use of command PROFIL in an execution sequence, the isotropic soil parameters of each soil type must be specified by use of command SOIL before any of the above mentioned commands may be used. Each time a new problem is introduced in an execution sequence by command PROFIL, the soil parameters describing soil types of preceding problems are no longer available for use.

Free-form Reader Error Codes

- FR01 - Data are insufficient to continue execution. An attempt was made to read beyond the last data item specified. Check for missing data items or for gaps between data items on each line larger than one blank space. This error only occurs at the end of an execution sequence within the data provided with the last command used.

- FR02 - The line of data displayed begins with one or more blank spaces or may be entirely blank. The first item of data of each line is required to begin in the first column. Lines entirely blank are not permitted.
- FR03 - Within the line of data displayed, a decimal point has been detected for a number read as an integer. An integer is not allowed to contain a decimal point. First check if any numbers intended to be integers contain a decimal point. If not, check if error is indirectly caused by a displacement of data read. Causes of displacements are discussed below.
- FR04 - Within the line of data displayed, a minus sign has been detected for a number read as an integer. All integers are required to be positive. Negative integers are never required as input for STABL. This error may be caused indirectly by displacement of data read. Causes of displacements are discussed below.
- FR05 - Within the line of data displayed, an illegal character has been detected for a number read as an integer. Only numeric characters and decimal points are allowed. If a command word is displayed, the data provided with the previous command was not sufficient to complete its execution. Check for a displacement of data read. Causes of displacements are discussed below.
- FR06 - Within the line of data displayed, a decimal point was not detected for a number read as a real number. A real number is required to contain a decimal point. First check if any numbers intended to be real numbers lack decimal points. If not, check if error is indirectly caused by a displacement of data read. Causes of displacements are discussed below.
- FR07 - Within the line of data displayed, an illegal character has been detected for a number read as a real number. Only numeric characters, decimal point, and minus sign are allowed. If a command word is displayed, the data provided with the previous command was not sufficient to complete its execution. Check for a displacement of data read. Causes of displacements are discussed below.

Displacements of data read are caused either by inadvertently omitting items of data or by leaving gaps between items of data larger than one blank space. Data items following a gap larger than one blank space are not read. Instead, data from the next line are read in their place, producing a displacement of data read from that point on.

At some point following the displacement, an error will be produced indirectly. A real number might be read as an integer, or vice versa, producing error FR03 or FR06 respectively. A negative real

number read as an integer will also produce error FRO4. When a displacement occurs, and if none of the above errors are produced, the numeric data will be exhausted and finally a command word will be read as numeric data producing error FRO5 or FRO7 depending upon whether an integer or real number was being read.

If cause of displacement is not found in the displayed line of data, check the preceding lines of data.

PROFIL Error Codes

- PF01 - The number of ground surface boundaries exceeds the total number of profile boundaries. The number of profile boundaries must be less than or equal to the total number of profile boundaries.
- PF02 - The number of profile boundaries specified may not exceed 100. The problem must be either redefined so fewer profile boundaries are used, or the dimensioning of the program must be increased to accommodate the problem so defined.
- PF03 - A negative coordinate has been specified for the profile boundary indicated. All problem geometry must be located within the 1st quadrant.
- PF04 - The coordinates of the end points of the profile boundary indicated have not been specified in the required order. The coordinates of the left end point must precede those of the right.
- PF05 - The ground surface boundaries indicated are not properly ordered or are not continuously connected. The ground surface boundaries must be specified from left to right and the ground surface described must be continuous.
- PF06 - The required subsurface boundary order is unsatisfied for the two boundaries indicated. Of boundaries which overlap horizontally, those above the others must be specified first.

WATER Error Codes

- WA01 - An attempt has been made to suppress or reactivate undefined water surface data. Data must be defined by a prior use of command WATER before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use whether the data are active or suppressed.

- WA02 - The number of points specified to define the water surface exceeds 40. The problem must be either redefined so fewer points are used, or the dimensioning of the program must be increased to accommodate the problem as defined.
- WA03 - Only one point has been specified to define the water surface. A minimum of two points is required.
- WA04 - A negative coordinate has been specified for the water surface point indicated. All problem geometry must be located within the 1st quadrant.
- WA05 - The water surface point indicates is not to the right of the points specified prior to it. The points defining the water surface must be specified in left to right order.

SURFAC Error Codes

- SF01 - The number of points specified to define a trial failure surface exceeds 100. The problem must be either redefined so fewer points are used, or the dimensioning of the program must be increased to accommodate the problem as defined.
- SF02 - Only one point has been specified to define the trial failure surface. A minimum of two points is required.
- SF03 - A negative coordinate has been specified for the trial failure surface point indicated. All problem geometry must be located within the 1st quadrant.
- SF04 - The trial failure surface point indicated is not to the right of the points specified prior to fit. The points defining the trial failure surface must be specified in left to right order, and no two points are allowed to define a vertical line.
- SF05 - The first point specified for the trial failure surface is not within the horizontal extent of the defined ground surface. All points defining a trial failure surface must be within the horizontal extent of the defined ground surface.

LIMITS Error Codes

- LM01 - An attempt has been made to suppress or reactivate undefined surface generation boundary data. Data must be defined by a prior use of command LIMITS before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use whether the data are active or suppressed.

- LM02 - The number of surface generation boundaries specified to deflect upward exceeds the total number of boundaries specified. The number of upward deflecting boundaries must not exceed the total number of boundaries.
- LM03 - The number of surface generation boundaries specified exceeds 20. The problem must be either redefined so fewer surface generation boundaries are used, or the dimensioning of the program must be increased to accommodate the problem as defined.
- LM04 - A negative coordinate has been specified for the surface generation boundary indicated. All problem geometry must be located within the 1st quadrant.
- LM05 - The coordinates of the end points of the surface generation boundary indicated have not been specified in the required order. The coordinates of the left end point must precede those of the right.

LOADS Error Codes

- LD01 - An attempt has been made to suppress or reactivate undefined surcharge boundary loads. Data must be defined by a prior use of command LOADS before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use, whether the data are active or suppressed.
- LD02 - The number of surcharge boundary loads specified exceeds 10. The problem must be either redefined so fewer loads are used, or the dimensioning of the program must be increased to accommodate the problem as defined.
- LD03 - A negative coordinate has been specified for the surcharge boundary load indicated. All problem geometry must be located within the 1st quadrant.
- LD04 - The X coordinates defining the horizontal extent of the surcharge boundary load indicated have not been specified in the required order. The X coordinate of the left end of the load must precede the X coordinate of the right end.
- LD05 - The surcharge boundary load indicated is not to the right of all the loads specified prior to it or overlaps one or more of them. The loads must be specified left to right and are not allowed to overlap.

SOIL Error Codes

- SL01 - The profile boundary indicated with the error message has an undefined soil type index. The number of soil types specified must be greater than or equal to each soil type index which has been assigned to profile boundaries.
- SL02 - The number of soil types may not exceed 20. The problem must be either redefined so fewer soil types are used, or the dimensioning of the program must be increased to accommodate the problem as defined.
- SL03 - An attempt has been made to change the parameters of one or more soil types which are undefined. No soil types have been defined since the last use of command PROFIL. When a new problem is introduced by command PROFIL, the soil parameters, describing soil types of preceding problems in the execution sequence, are no longer available for use and cannot therefore be changed.
- SL04 - The number of soil types to be changed is greater than the total number of soil types already defined. This implies changing isotropic soil parameters of soil types which have not been specified and therefore is not permitted. The number of soil types to be changed must be less than or equal to the number of soil types specified by a previous use of command SOIL. Each soil type must be previously specified, before its parameters may be changed.
- SL05 - An attempt has been made to change the parameters describing an unspecified soil type. The soil type must be defined before it may be modified. The index of each soil type to be changed must be less than the total number of soil types.

ANISO Error Codes

- A101 - An attempt has been made to suppress or reactivate undefined anisotropic strength data. Data must be defined by a prior use of command ANISO before they can be suppressed. Suppressed data can not be reactivated if command PROFIL has been used in the execution sequence subsequent to their suppression. Command PROFIL nullifies all data read prior to their use whether the data are active or suppressed.
- A102 - The number of anisotropic soil types specified may not exceed the number of soil types specified by command SOIL.
- A103 - The number of anisotropic soil types specified exceeds 5. The problem must be either redefined so fewer anisotropic soil types are used, or the dimensioning of the program must be increased to accommodate the problem as defined.

- A104 - The soil type index indicated is greater than the number of soil types specified by command SOIL. The index of each anisotropic soil type must be less than or equal to the number of soil types specified.
- A105 - The number of direction ranges specified for the anisotropic soil type indicated is less than 2 or exceeds 10. No soil type should be defined anisotropic with number of direction ranges less than 2, as this means soil is isotropic. Also no soil type should exceed 10 direction ranges. If this is desired, the dimensions of the program must be increased.
- A106 - The counterclockwise limit of each direction range must be specified in counterclockwise order, if the anisotropic strength is to be properly defined for the anisotropic soil type indicated.
- A106 - The total direction range for the anisotropic soil type indicated has not been completely defined. The counterclockwise limit of the last direction range specified must be 90 degrees.

RANDOM and CIRCLE Error Codes

- RC01 - The first initiation point lies to the left of the defined ground surface. The x coordinate of the first initiation point must be specified so all trial failure surfaces generated will intersect the defined ground surface when they initiate.
- RC02 - The first and last initiation points are not correctly specified. They must be specified in left-right order.
- RC03 - The last initiation point lies to the right of the defined ground surface. The x coordinate of the last initiation point must be specified so all trial failure surfaces generated will intersect the defined ground surface when they initiate.
- RC04 - The right termination limit lies to the right of the defined ground surface. The right termination limit must be specified so all trial failure surfaces generated will intersect the defined ground surface when they terminate.
- RC05 - The left and right termination limits are not correctly specified. They must be specified in left-right order.
- RC06 - The last initiation point lies to the right of the right termination limit. It is impossible to successfully generate any trial failure surfaces, when the initiation point lies to the right of the right termination limit.

- RC07 - The depth limitation for trial failure surface development is negative. The depth limitation must be set at or above the x axis so the generated trial failure surfaces will not be allowed to develop below it.
- RC08 - The length specified for the line, segments used to generate trial failure surfaces is less than or equal to zero. The length must be greater than zero.
- RC09 - An initiation point is below the depth limitation. The depth limitation must be set lower to enable the successful generation of trial failure surfaces from all initiation points.
- RC10 - The number of points defining a generated trial failure surface exceeds 100. The length specified for the line segments must be increased.
- RC11 - 200 attempts to generate a single trial failure surface have failed. The search limitations are either too restrictive, or they actually prevent successful generation of a trial failure surface from one or more of the initiation points. Check and revise the search limitations or use an alternative trial surface generator.
- RC12 - Fewer than 10 trial failure surfaces have been specified to be generated. A minimum of 10 must be generated.

BLOCK Error Codes

- BK01 - The number of boxes specified for a sliding block search exceeds 10. The problem must be either redefined so fewer points are used, or the dimensioning of the program must be increased to accommodate the problem as defined.
- BK02 - The length specified for the line segments used to generate the active and passive portions of the trial failure surfaces is less than or equal to zero. The length must be greater than zero.
- BK03 - The two coordinate points specified to define the centerline of the box indicated have not been specified correctly. The left point must be specified first.
- BK04 - The box indicated and the one specified before it are not properly ordered, or they overlap. All boxes must be specified in left to right order and the boxes are not allowed to overlap one another.

- BK05 - The box indicated is wholly or partially defined outside of the 1st quadrant. All problem geometry must be located within the 1st quadrant.
- BK06 - The box indicated is wholly or partially above the defined ground surface. Each box must be defined totally below the ground surface.
- BK07 - It is not possible to complete the active portion of the failure surface from part of or all of the last box specified. The last box specified must be entirely to the left of the right end of the defined ground surface.
- BK08 - It is not possible to complete the passive portion of the failure surface from part of or all of the first box specified. The first box specified must be entirely to the right of a fictitious line extended downward at forty-five degrees with horizontal from the left end of the defined ground surface.
- BK09 - The number of points defining a generated trial failure surface exceeds 100. The length specified for the line segments of the active and passive portions of the generated trial failure surfaces must be increased.
- BK10 - 200 attempts to generate a single trial failure surface have failed. The search limitations are either too restrictive or they actually prevent successful generation of a trial failure surface. Check and revise the search limitations or use an alternate trial surface generator.
- BK11 - Fewer than 10 trial failure surfaces have been specified to be generated. A minimum of 10 must be generated.
- BK12 - The point(s) calculated on active or passive portion of the sliding block is not within the horizontal extent of the defined ground surface. Either the specified boxes should be changed or the geometry of the problem should be extended to include the point(s) in question.

EXAMPLE PROBLEM

This example concerns the long term stability of a cut in a soft clay material (Figure 17). Without worrying about the validity of such a problem, let it be defined as follows for illustration.

A ground water table is present at a depth of about 17 feet below the existing ground surface which gently slopes toward the cut. An irregular bedrock surface lies at a relatively shallow depth. The variation of the bedrock surface normal to the plane of the profile is insignificant. Therefore a two-dimensional analysis is assumed appropriate.

The shear parameters ($c' = 500$ psf, $\phi = 14^\circ$) do not vary significantly with depth, but due to desiccation, tension cracks are assumed to extend to a depth of approximately 11 feet.

By defining the problem geometry with straight lines (Figure 18) the problem can be handled by STABL. The total number of boundaries defined by command PROFIL is six, of which five define the ground surface. A subsurface boundary is used to differentiate a zone containing tension cracks from the remaining clay material. The boundaries are ordered ground surface boundaries first, left to right, with the single subsurface boundary last, satisfying program requirements. The 4th and 5th boundaries on the ground surface are above the tension crack zone, so they are assigned a different soil type number from that assigned to the other boundaries. The clay below the

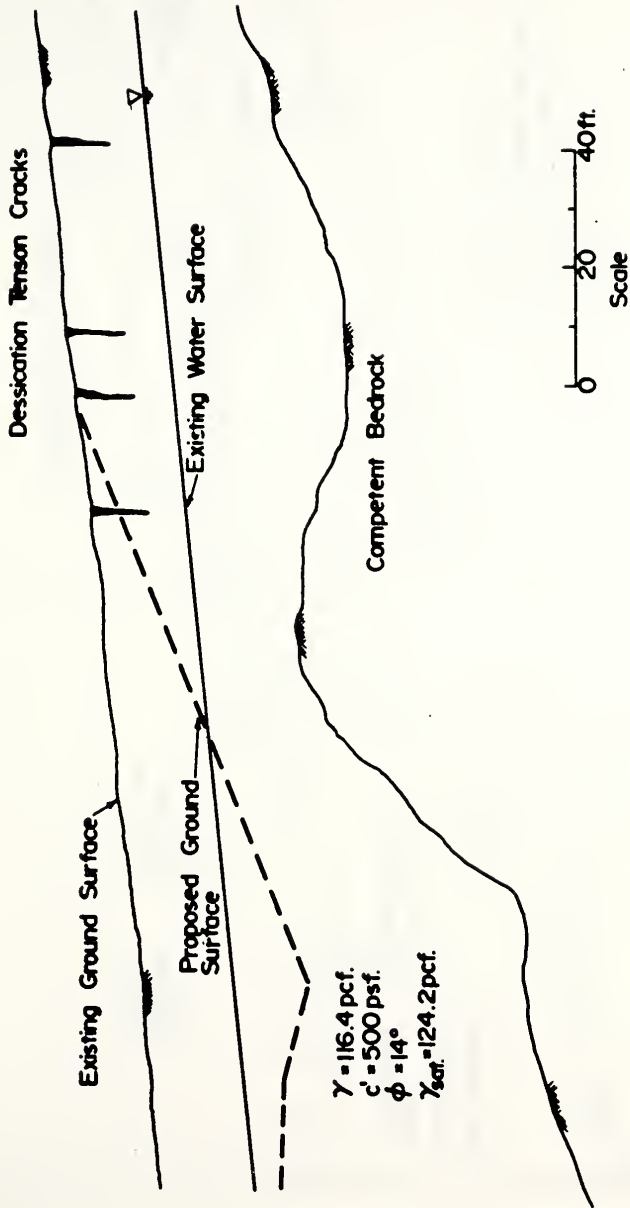


FIGURE 17- EXAMPLE PROBLEM.

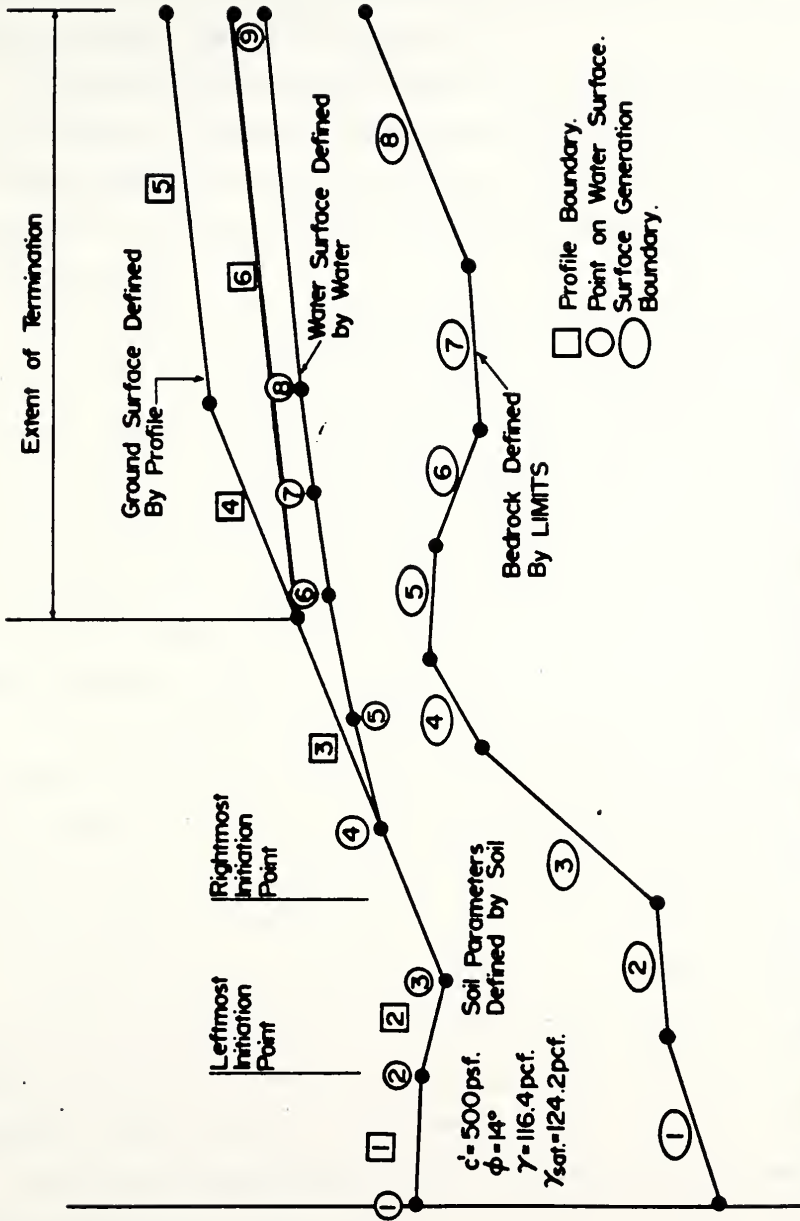


FIGURE 18-LINEAR APPROXIMATION OF EXAMPLE PROBLEM.

tension zone has been arbitrarily assigned soil type number 1 and that within the tension zone, soil type number 2.

The bedrock has been assumed competent, with no possibility of failure within it. Therefore, surface generation boundaries, defined by command LIMITS, are used to approximate the bedrock surface. Generation of trial failure surfaces which pass through the bedrock is thus prevented.

It would also have been possible to define the bedrock surface with additional subsurface boundaries defined by command PROFIL. A third soil type with appropriate strength parameters would have been then assigned. The factor of safety of surfaces generated through the bedrock would have been obviously much higher than those above it. The alternative would have been wasteful, and therefore has not been used for this example. However it could have been applicable if the bedrock material was weak.

Of the eight surface generation boundaries which are specified, all eight will deflect generating surfaces upward. The boundaries are therefore not required to be specified in any specific order. However, to maintain consistency, they have been specified in continuous order from left to right.

The water surface is defined by eight points, of which the first four lie at the ground surface. The remaining points have been adjusted to account for response of the ground water table to the change in boundary conditions introduced by the cut.

The two soil types assigned to the boundaries defined by command PROFIL are defined by command SOIL in order of soil type number. Soil

type 1 has shear strength parameters of $c' = 500$ psf and $\phi' = 14$ deg. Soil type 2, since it is in tension, is assigned zero shear strength parameters. The total unit weight of both soil types is 116.4 pcf. The saturated unit weight of soil type 1 is 124.2 pcf, and that of soil type 2 has been arbitrarily been assigned 116.4 pcf. The saturated unit weight of soil type 2 will not be used in the analysis however, as soil type 2 is entirely above the water surface. The pore pressure constant and pore pressure parameter for both soil types are not used in this example, so they are assigned zero values.

Searching for the critical surface will be carried out using each of the three trial failure surface generators. Normally, only one generator, or a combination of two, would be used for most problems, but it is instructive to demonstrate the use of each for the same problem. Circular shaped trial failure surfaces are generated and evaluated first by use of command CIRCLE.

It is doubtful that a failure surface would initiate beyond the toe of the slope, because of the controlling influence of the bedrock surface. Since the search is restricted to circular shaped surfaces, the influence of the bedrock may, in fact, force the critical circular surface to pass through a point on the face of the slope, rather than at the toe of the slope or beyond.

Somewhat arbitrarily, it is decided to generate a total of one hundred surfaces; ten surfaces from each of ten initiation points. The leftmost initiation point is positioned at the toe of the slope, $x = 38$ ft, and the rightmost on the face of the slope at $x = 70$ ft.

The termination limits are also somewhat arbitrarily selected. Usually, the critical surface of a slope will pass a short distance behind the crest of a slope. However, the bedrock may force the critical surface to be located short of the crest. The left termination limit is set at $x = 120$ ft to allow for this possibility. The right termination limit is set at $x = 180$ ft. If later, the ten most critical surfaces are found to congregate at either limit, the termination limits can be revised for subsequent runs.

The depth limitation is not required, because the bedrock surface, as defined by surface generation boundaries, prevents the generation of deep failure surfaces. It must be specified, however, and for this example, it is set at $y = 0$.

The length of the line segments defining the circular shaped surfaces is set at ten feet. This is one-fourth of the height of the slope. Lengths one-fourth to one-half the height of the slope are generally reasonable. The length specified for the line segments has a direct influence on computation time. Although short line segments define circular surfaces more accurately, they require more computation time for surface generation and the factor of safety calculation.

No restrictions are placed upon the angle of inclination of the initial line segment. Therefore both the clockwise and counterclockwise inclination limits are specified as zero.

A listing of the raw input data, found on the next page, is shown as it would be prepared for the problem as described. Note that all the data begins in the first column; the commands are on individual lines; the data items on each line are separated by single blank

Data Set Up for Example Problem for Revised STABL Program

(replaces previous problem in STABL Users Manual p. 67 ff)

```

PROFIL
EXAMPLE PROBLEM
23 11
0. 46. 10. 46. 4
10. 46. 17. 42. 4
17. 42. 26. 42. 4
26. 42. 34. 46. 4
34. 46. 56. 45. 4
56. 45. 90. 56. 1
90. 56. 145. 75. 2
145. 75. 156. 76. 2
156. 76. 240. 105. 1
240. 105. 259. 108. 1
259. 108. 320. 108. 1
156. 76. 320. 78. 2
90. 56. 320. 59. 1
56. 45. 216. 38. 4
216. 38. 320. 43. 4
0. 36. 20. 36. 5
20. 36. 136. 29. 5
136. 29. 216. 32. 5
216. 32. 320. 28. 5
0. 22. 136. 22. 4
0. 17. 31. 17. 1
31. 17. 136. 22. 1
136. 22. 320. 22. 1
SOIL
5
125. 125. 0. 35. 0. 0. 1
125. 125. 0. 33. 0. 0. 1
125. 125. 0. 35. 0. 0. 1
122. 122. 320. 29. 0. 0. 2
122. 122. 740. 16. 0. 0. 2
WATER
2 0.
5
0. 45. 56. 45.
126. 51. 216. 47.
320. 47.
7
0. 45. 56. 45.
126. 51. 136. 60.
150. 64. 250. 112.
320. 110.
BLOCK2
50 2 50.
50. 29. 90. 26. 8.
140. 26. 280. 26. 6.

```


OUTPUT

--SLOPE STABILITY ANALYSIS--
 MODIFIED BISHOP METHOD OF SLICES
 IRREGULAR FAILURE SURFACES

PROBLEM DESCRIPTION EXAMPLE PROBLEM

BOUNDARY COORDINATES

11 TOP BOUNDARIES
 23 TOTAL BOUNDARIES

BOUNDARY NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)	SOIL TYPE BELOW END
1	0	46.00	10.00	46.00	4
2	10.00	46.00	17.00	42.00	4
3	17.00	42.00	26.00	42.00	4
4	26.00	42.00	34.00	46.00	4
5	34.00	46.00	56.00	45.00	4
6	56.00	45.00	90.00	56.00	1
7	90.00	56.00	145.00	75.00	2
8	145.00	75.00	156.00	76.00	2
9	156.00	76.00	240.00	105.00	1
10	240.00	105.00	259.00	108.00	1
11	259.00	108.00	320.00	108.00	1
12	156.00	76.00	320.00	78.00	2
13	90.00	56.00	320.00	58.00	1
14	56.00	45.00	216.00	38.00	4
15	216.00	38.00	320.00	43.00	4
16	0	36.00	20.00	36.00	5
17	20.00	36.00	136.00	29.00	5
18	136.00	29.00	216.00	32.00	5
19	216.00	32.00	320.00	28.00	5
20	0	22.00	136.00	22.00	4
21	0	17.00	31.00	17.00	1
22	31.00	17.00	136.00	22.00	1
23	136.00	22.00	320.00	22.00	1

ISOTROPIC SOIL PARAMETERS

5 TYPE(S) OF SOIL

SOIL TYPE NO.	TOTAL UNIT WT. (PCF)	SATURATED UNIT WT. (PCF)	COHESION INTERCEPT (PSF)	FRICTION ANGLE (DEG)	PORE PRESSURE PARAMETER	PRESSURE CONSTANT (PSF)	PIEZOMETRIC SURFACE NO.
1	125.0	125.0	0	35.0	0	0	1
2	125.0	125.0	0	33.0	0	0	1
3	125.0	125.0	0	35.0	0	0	1
4	122.0	122.0	320.0	29.0	0	0	2
5	122.0	122.0	740.0	16.0	0	0	2

2 PIEZOMETRIC SURFACE(S) HAVE BEEN SPECIFIED

UNITWEIGHT OF WATER = 62.40

PIEZOMETRIC SURFACE NO. 1 SPECIFIED BY 5 COORDINATE POINTS

POINT NO.	X-WATER (FT)	Y-WATER (FT)
1	0	45.00
2	56.00	45.00
3	126.00	51.00
4	210.00	47.00
5	320.00	47.00

PIEZOMETRIC SURFACE NO. 2 SPECIFIED BY 7 COORDINATE POINTS

POINT NO.	X-WATER (FT)	Y-WATER (FT)
1	0	45.00
2	56.00	45.00
3	126.00	51.00
4	136.00	60.00
5	150.00	64.00
6	250.00	112.00
7	320.00	110.00

A CRITICAL FAILURE SURFACE SEARCHING METHOD, USING A RANDOM TECHNIQUE FOR GENERATING SLIDING BLOCK SURFACES, HAS BEEN SPECIFIED.

THE ACTIVE AND PASSIVE PORTIONS OF THE SLIDING SURFACES ARE GENERATED ACCORDING TO THE RANKINE THEORY.

50 TRIAL SURFACES HAVE BEEN GENERATED.

2 BOXES SPECIFIED FOR GENERATION OF CENTRAL BLOCK BASE

LENGTH OF LINE SEGMENTS FOR ACTIVE AND PASSIVE PORTIONS OF SLIDING BLOCK IS 50.0

BOX NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)	WIDTH (FT)
1	50.00	29.00	90.00	26.00	8.00
2	140.00	26.00	280.00	26.00	6.00

FOLLOWING ARE DISPLAYED THE TEN MOST CRITICAL OF THE TRIAL FAILURE SURFACES EXAMINED. THEY ARE ORDERED - MOST CRITICAL FIRST.

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	52.43	45.16
2	73.46	32.77
3	86.96	22.61
4	211.84	26.69
5	215.84	31.99
6	219.47	38.17
7	229.39	57.21
8	240.15	77.03
9	256.03	107.53

*** 1.658 ***

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	39.19	45.76
2	59.85	33.60
3	69.02	26.68
4	212.99	25.05
5	218.17	31.92
6	221.92	33.28
7	231.78	57.23
8	242.55	77.06
9	258.62	107.94

*** 1.678 ***

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	29.76	43.88
2	45.78	34.44
3	55.09	27.43
4	218.26	23.08
5	224.74	31.66
6	228.83	38.62
7	238.55	57.29
8	249.33	77.14
9	265.39	103.00

*** 1.691 ***

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	32.78	45.39
2	51.99	34.07
3	59.31	28.56
4	220.04	23.65
5	226.04	31.61
6	230.20	38.68
7	239.89	57.30
8	250.67	77.15
9	266.73	108.00

*** 1.696 ***

FAILURE SURFACE SPECIFIED BY 10 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	58.03	45.66
2	59.59	44.84
3	80.83	32.33
4	86.95	27.72
5	225.52	25.34
6	230.13	31.46
7	234.51	33.89
8	244.11	57.34
9	254.90	77.21
10	270.93	108.00

*** 1.697 ***

FAILURE SURFACE SPECIFIED BY 10 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	58.60	45.84
2	60.60	44.80
3	81.88	32.27
4	89.76	26.32
5	230.83	26.86
6	234.18	31.30
7	238.77	39.09
8	248.29	57.38
9	259.08	77.26
10	275.09	108.00

*** 1.701 ***

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	39.15	45.77
2	59.81	33.60
3	67.11	28.09
4	228.59	28.53
5	230.78	31.43
6	235.19	38.92
7	244.78	57.35
8	255.57	77.21
9	271.59	108.00

*** 1.710 ***

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	28.80	43.40
2	43.80	34.56
3	52.74	27.83
4	222.28	25.37
5	226.96	31.58
6	231.17	38.73
7	240.84	57.31
8	251.62	77.17
9	267.67	108.00

*** 1.714 ***

FAILURE SURFACE SPECIFIED BY 10 COORDINATE POINTS

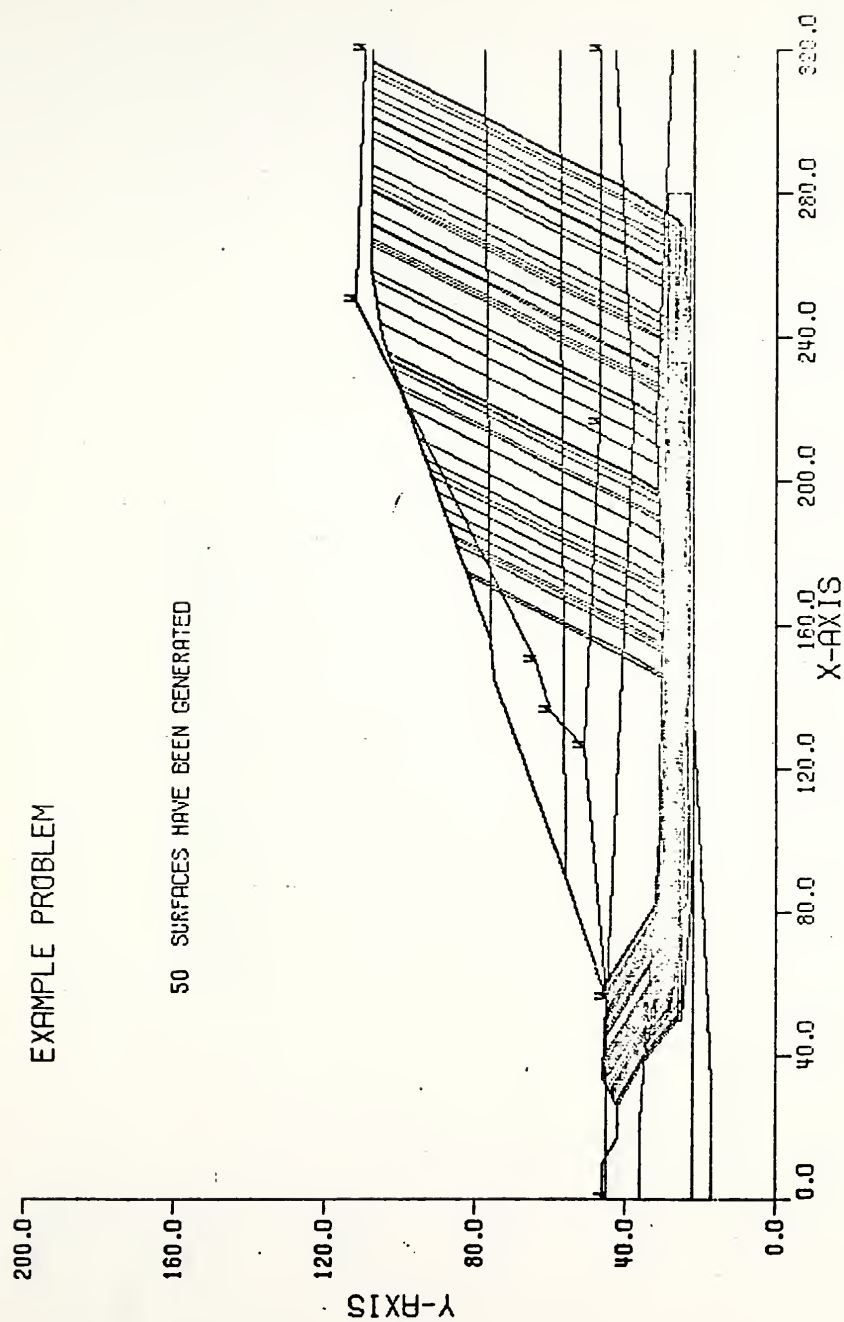
POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	56.32	45.10
2	56.56	44.98
3	77.71	32.52
4	84.40	27.48
5	238.81	27.56
6	241.41	31.02
7	246.39	39.46
8	255.74	57.44
9	266.55	77.35
10	282.51	108.00

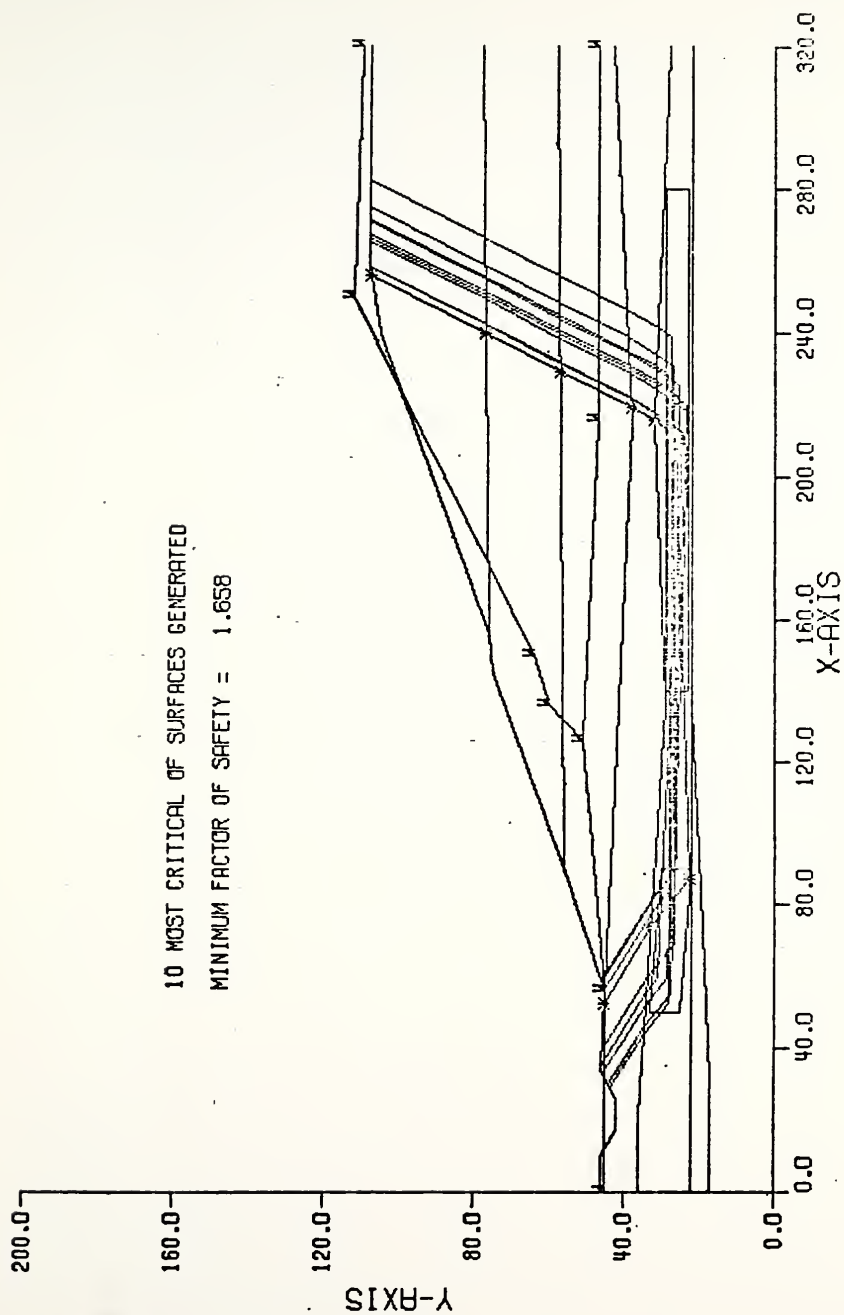
*** 1.725 ***

FAILURE SURFACE SPECIFIED BY 9 COORDINATE POINTS

POINT NO.	X-SURF (FT)	Y-SURF (FT)
1	35.03	45.95
2	55.57	33.85
3	59.55	30.85
4	212.46	24.48
5	218.07	31.92
6	221.81	38.28
7	231.68	57.23
8	242.44	77.05
9	258.51	107.92

*** 1.728 ***





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spaces; and real and integer numeric data, respectively, do and do not contain decimal points.

Following the listing of the raw input data is the output for the commands executed for the first run. The last information printed is the print character plot of the problem resulting from the use of command CIRCLE. Two additional plots, prepared by a Gould electrostatic plotting device, are also included. All the input data, associated with each command used, is displayed with the output. The coordinates of the ten most critical surfaces along with their respective factors of safety are printed when search commands are used.

The print character plot contains information regarding the input data and the surfaces generated. The line segments connecting points can be sketched in for clearer interpretation. The ten most critical of the surfaces generated appear as strings of one digit numbers, while the remaining surfaces generated appear as dots.

From this plot the ten most critical surfaces are found to be located within the extent of all the surfaces generated. This indicates a fairly good choice of initial restraints used to generate the surfaces.

The two Gould plots show basically the same information as the print character plot, but in a form more easily interpreted. The first of these plots shows the extent of the surfaces generated, while the second displays the ten most critical. No distinction is made of the criticality of each surface, so one must refer to the print character plot or to the printed output of the coordinates of these ten surfaces.

The values of the factors of safety of the ten most critical surfaces range from 1.32 to 1.36. This is not a large difference, and the chances of locating a circular shaped surface with a factor of safety much less than 1.32 is probably small. The width of the zone occupied by these critical surfaces at the toe and crest indicates that the bedrock influences the stability of the slope by making the value of the factor of safety relatively insensitive to the position of a circular shaped surface, as long as the surface passes near the bedrock surface.

A tendency can be observed that the more critical surfaces of the ten generated occur nearer the toe of the slope. Therefore, there is a good possibility that the critical surface passes through the toe. A second run is made to check this possibility.

Twenty-five surfaces are generated from each of 3 initiation points; the leftmost again at the toe, and the rightmost at $x = 50$ ft. The rightmost initiation point is moved, because critical surfaces were not determined for the right initiation points in the first run. If a circular surface through the toe is critical, then most of the critical surfaces subsequently determined should pass through the toe. The total number of surfaces to be generated, 75, should be adequate because the surfaces generated will be required to satisfy stricter requirements. All surfaces to be generated for the second run will lie in a zone somewhat matching that of the ten most critical surfaces of the first run.

All except one of the critical circular surfaces, determined by the first run, lie behind the crest of the slope, so the left

termination limit is moved to the crest at $x = 138$ ft. Also, all the critical surfaces do not extend beyond $x = 170$ ft, except one, which does so just barely. Therefore, the right termination limit is changed to that position.

Since the minimum angle of inclination of the initial line segments of the critical surfaces is about -21° , and no angle exceeded 0° , the inclination angle will be restricted between 0° and -25° .

Because the critical surfaces of the first run all lie at or near the bedrock surface, it would be efficient to prevent generation of surfaces at shallower depths. This is accomplished by blocking the generation of such surfaces with downward deflecting surface generation boundaries. One boundary is fixed between a point at the ground surface to the right of the last initiation point (63., 73.) and a point a short distance above the bedrock surface (93., 67.). Another is specified between this last point and the crest.

Having modified the requirements each generated surface must satisfy, the second random search was performed using circular surfaces. The next page contains the listing of the raw input for this run.

Following the listing of the raw input data, the output is partially displayed. Since no changes were made to the input data for commands PROFIL, SOIL, and WATER, the output data associated with these commands are omitted. Also, since the output of coordinates for points defining each of the ten most critical surfaces is somewhat bulky, it is omitted. The print character plot and Gould plots should be sufficient.

INPUT FOR SECOND RUN -

PROFIL
 EXAMPLE PROBLEM
 6 5
 0. 68. 22. 67. 1
 22. 67. 38. 63. 1
 38. 63. 101. 88. 1
 101. 88. 138. 103. 2
 138. 103. 205. 110. 2
 101. 88. 205. 99. 1
 SOIL
 2
 116.4 124.2 500. 14. 0. 0.
 116.4 116.4 0. 0. 0. 0.
 WATER
 9
 0. 68.
 22. 67.
 38. 63.
 63. 73.
 88. 78.
 104. 82.
 122. 85.
 140. 87.
 205. 93.
 LIMITS
 10 8
 0. 15. 29. 24.
 29. 24. 51. 26.
 51. 26. 78. 56.
 78. 56. 94. 65.
 94. 65. 113. 64.
 113. 64. 133. 56.
 133. 56. 161. 58.
 161. 58. 205. 76.
 63. 73. 93. 67.
 93. 67. 138. 103.
 CIRCLE
 3 25 38. 50. 138. 170. 0. 10. 0. -25.

PARTIAL OUTPUT FOR SECOND RUN -

SEARCHING ROUTINE WILL BE LIMITED TO AN AREA DEFINED BY 10 BOUNDARIES
OF WHICH THE FIRST 8 BOUNDARIES WILL DEFLECT SURFACES UPWARD

BOUNDARY NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)
1	0	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00
9	63.00	73.00	93.00	67.00
10	93.00	67.00	138.00	103.00

A CRITICAL FAILURE SURFACE SEARCHING METHOD, USING A RANDOM
TECHNIQUE FOR GENERATING CIRCULAR SURFACES, HAS BEEN SPECIFIED.

75 TRIAL SURFACES HAVE BEEN GENERATED.

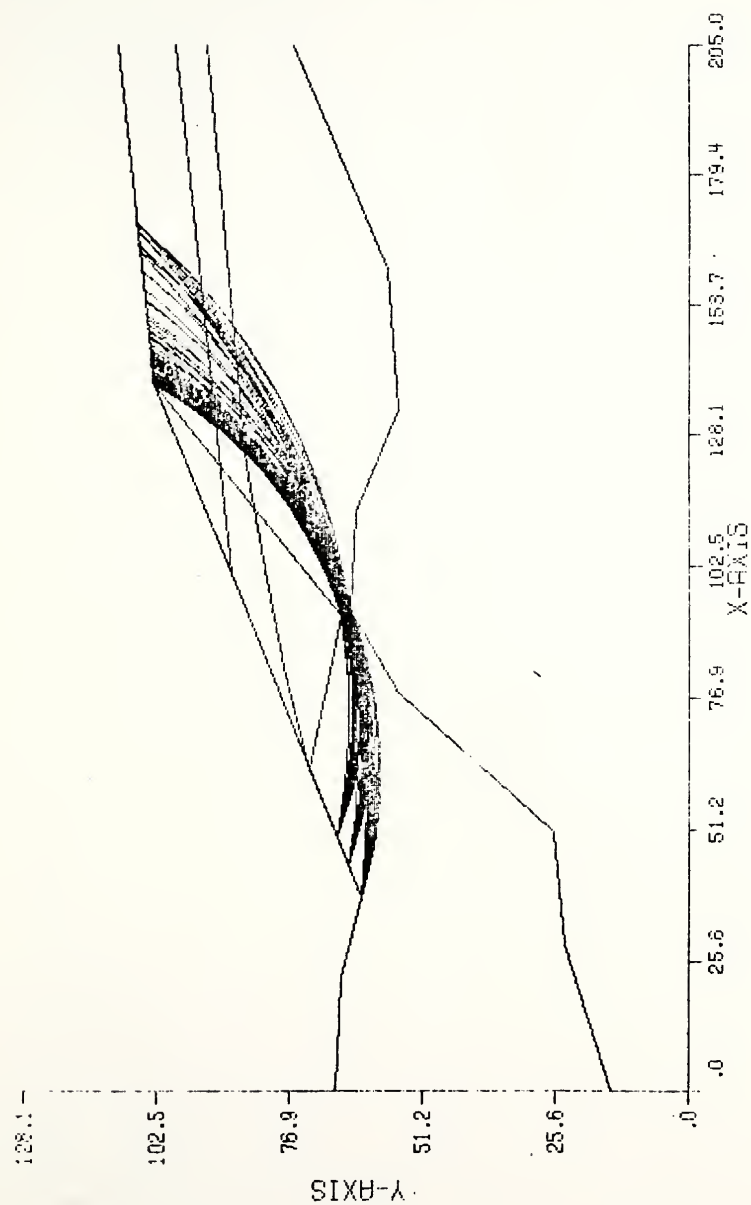
25 SURFACES INITIATE FROM EACH OF 3 POINTS EQUALLY SPACED
ALONG THE GROUND SURFACE BETWEEN X = 38.00 FT.
AND X = 50.00 FT.

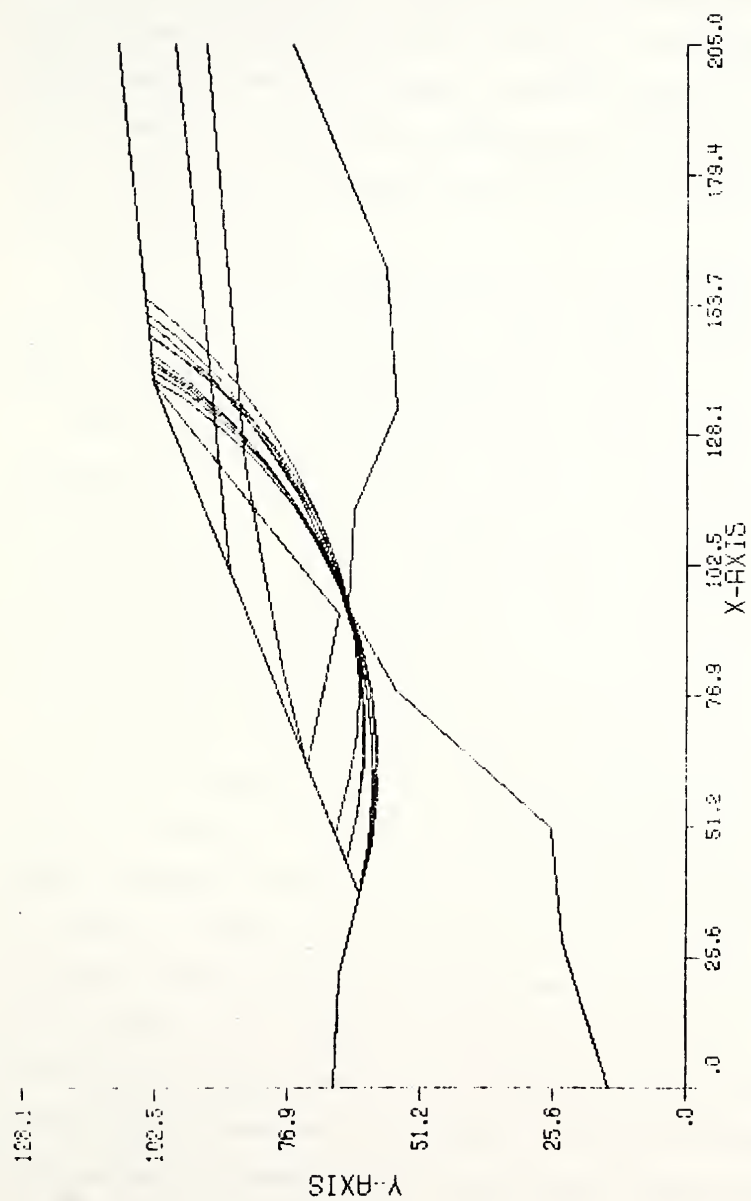
EACH SURFACE TERMINATES BETWEEN X = 138.00 FT.
AND X = 170.00 FT.

UNLESS FURTHER LIMITATIONS WERE IMPOSED, THE MINIMUM ELEVATION
AT WHICH A SURFACE EXTENDS IS Y = 0 FT.

10.00 FT. LINE SEGMENTS DEFINE EACH TRIAL FAILURE SURFACE.

RESTRICTIONS HAVE BEEN IMPOSED UPON THE ANGLE OF INITIATION.
THE ANGLE HAS BEEN RESTRICTED BETWEEN THE ANGLES OF -25.0 AND 0 DEG





The range of values obtained for the ten most critical surfaces is 1.25 to 1.28. The difference is smaller, and all values are smaller in magnitude than those obtained from the first run. The ten most critical surfaces form a more compact zone than observed in the plots of the first run. Seven of these surfaces pass through the toe of the slope, and of these seven surfaces, five are more critical than the other three which do not.

There is little justification to refine the search limitations further for another run using circular shape surfaces, so irregular shaped surfaces will be generated and analyzed next.

Using information obtained from analyzing circular surfaces, it is assumed that the critical irregular surface will pass through the toe, and that it will lie near or at the bedrock surface. From the toe of the slope 30 irregular shaped surfaces are randomly generated. Only 30 surfaces may seem inadequate, but it is more than what was generated from the toe of the slope for the second run.

All the critical circular surfaces of the second run terminated to the left of the point $x = 160$ ft, so the right termination limit is moved to that position. The length of the line segments to define the irregular surfaces is specified as 15 ft. The angle of inclination of the initial line segment is restricted between -15° and -45° . Although the circular search indicated shallower angles of inclination for the critical surface, it is thought that the initial inclination is controlled by the circular shape of the surfaces generated, and if the surfaces were not restricted to this shape, the angle of inclination of the initial line segment of the critical surface could be steeper.

The listing of the raw input data and a portion of the output for the third run follow on the next pages. The range in values of the factor of safety for the ten most critical irregular surfaces is 1.23 to 1.27, a reduction compared to that determined when restricted to circular surfaces.

Viewing the Gould plot of the ten most critical irregular surfaces, it can be observed that these surfaces have steeper angles at inclination for the initial line segments. The initial line segment of the most critical irregular surface is inclined at about 33.5° . Note the fairly compact zone. Tightening the surface generation requirements would be of little benefit for ~~another run~~ using the irregular surface generator. An application of the sliding block generator would be better.

The position of the most critical surface of the third run is used as the **probable** location of the most critical surface. Nine degenerate boxes are specified along the path of this surface. They are specified from left to right in a manner so they do not overlap.

The first box on the left is specified as a point at the toe of the slope. The next three boxes are specified as vertical lines, 4 feet long, straddling the critical irregular surface. The fifth box is also specified as a vertical line, but its length is specified as only 2 feet. Due to the proximity of the bedrock surface, it is positioned just above the bedrock. The sixth box is specified as a point just above the bedrock surface at the high point. The next two points are again specified as 4 foot vertical line segments, straddling the critical surface. The final box is specified as a horizontal line

INPUT FOR THIRD RUN -

```

PROFIL
EXAMPLE PROBLEM
6 5
0. 68. 22. 67. 1
22. 67. 38. 63. 1
38. 63. 101. 88. 1
101. 88. 138. 103. 2
138. 103. 205. 110. 2
101. 88. 205. 99. 1
SOIL
2
116.4 124.2 500. 14. 0. 0.
116.4 116.4 0. 0. 0. 0.
WATER
9
0. 68.
22. 67.
38. 63.
63. 73.
83. 78.
104. 82.
122. 85.
140. 87.
205. 93.
LIMITS
10 8
0. 15. 29. 24.
29. 24. 51. 26.
51. 26. 78. 56.
78. 56. 94. 65.
94. 65. 113. 64.
113. 64. 133. 56.
133. 56. 161. 58.
161. 58. 205. 76.
40.5 64. 93. 68.
93. 68. 138. 103.
RANDOM
1 30 38. 38. 138. 160. 0. 15. -15. -45.

```


PARTIAL OUTPUT FOR THIRD RUN -

SEARCHING ROUTINE WILL BE LIMITED TO AN AREA DEFINED BY 10 BOUNDARIES
OF WHICH THE FIRST 8 BOUNDARIES WILL DEFLECT SURFACES UPWARD

BOUNDARY NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)
1	0	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00
9	40.50	64.00	93.00	68.00
10	93.00	68.00	138.00	103.00

A CRITICAL FAILURE SURFACE SEARCHING METHOD, USING A RANDOM
TECHNIQUE FOR GENERATING IRREGULAR SURFACES, HAS BEEN SPECIFIED.

30 TRIAL SURFACES HAVE BEEN GENERATED.

30 SURFACES INITIATE FROM EACH OF 1 POINTS EQUALLY SPACED
ALONG THE GROUND SURFACE BETWEEN X = 38.00 FT.
AND X = 38.00 FT.

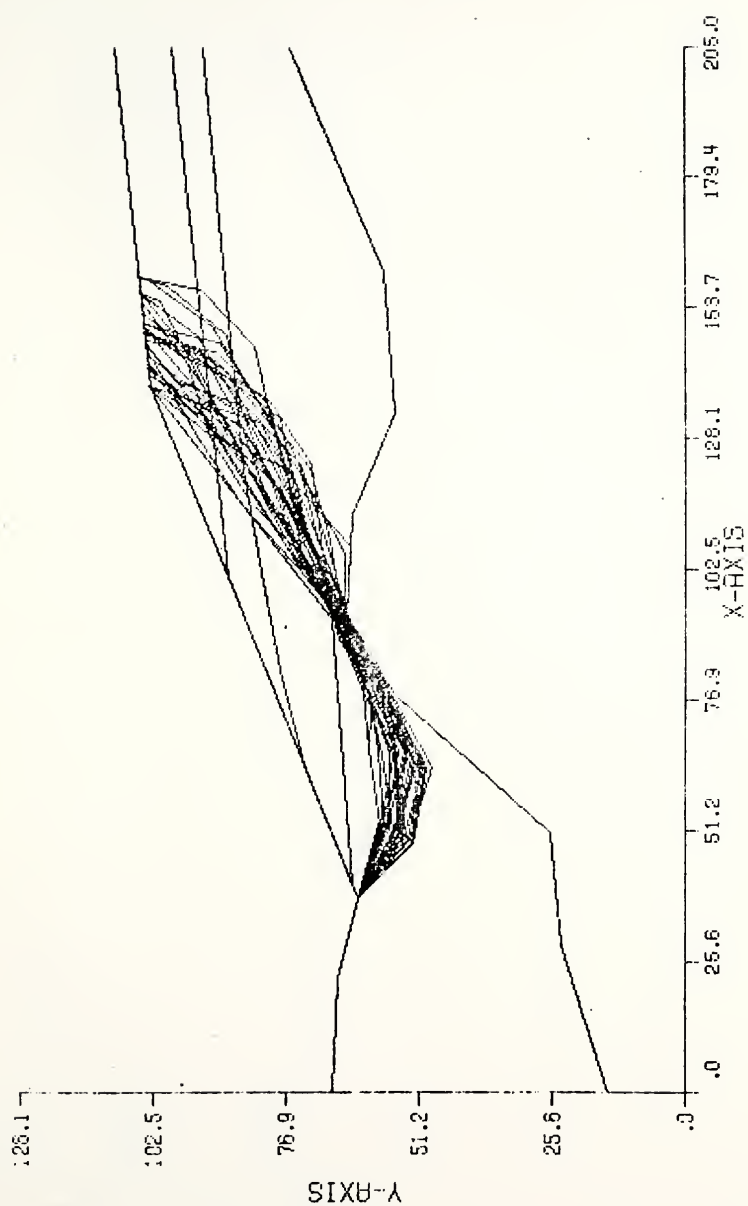
EACH SURFACE TERMINATES BETWEEN X = 138.00 FT.
AND X = 160.00 FT.

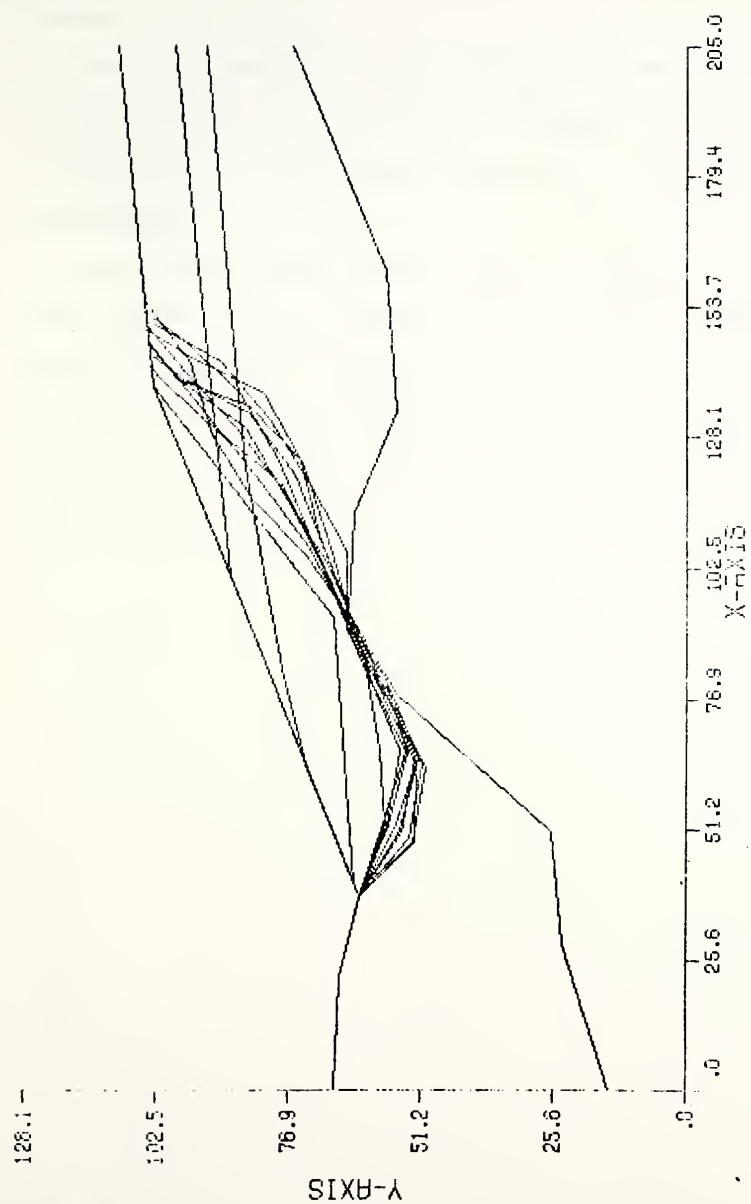
UNLESS FURTHER LIMITATIONS WERE IMPOSED, THE MINIMUM ELEVATION
AT WHICH A SURFACE EXTENDS IS Y = 0 FT.

15.00 FT. LINE SEGMENTS DEFINE EACH TRIAL FAILURE SURFACE.

RESTRICTIONS HAVE BEEN IMPOSED UPON THE ANGLE OF INITIATION.
THE ANGLE HAS BEEN RESTRICTED BETWEEN THE ANGLES OF -45.0 AND -15.0 DG :

FOLLOWING ARE DISPLAYED THE TEN MOST CRITICAL OF THE TRIAL
FAILURE SURFACES EXAMINED. THEY ARE ORDERED - MOST CRITICAL
FIRST.





segment, 5 feet in length, again straddling the critical irregular surface.

Points are randomly picked from within each box in sequence and connected to form part of a surface. To complete the active portion of a surface, 20 ft line segments are specified. Two-hundred surfaces are generated.

The listing of the raw input data and a portion of the generated output follow on the next pages. The values of the factor of safety ranged from 1.203 to 1.206 for the ten most critical surfaces, and the ten most critical surfaces form a very tight zone. Note the relative position of these surfaces with respect to the boxes, which can be seen in the second Gould plot. Another run would not be justified.

INPUT FOR FOURTH RUN -

```

PROFIL
EXAMPLE PROBLEM
6 5
0. 68. 22. 67. 1
22. 67. 38. 63. 1
38. 63. 101. 88. 1
101. 88. 138. 103. 2
138. 103. 205. 110. 2
101. 88. 205. 99. 1
SOIL
2
116.4 124.2 500. 14. 0. 0.
116.4 116.4 0. 0. 0. 0.
WATER
9
0. 68.
22. 67.
38. 63.
63. 73.
83. 78.
104. 82.
122. 85.
140. 87.
205. 93.
LIMITS
8 8
0. 15. 29. 24.
29. 24. 51. 26.
51. 26. 78. 56.
78. 56. 94. 65.
94. 65. 113. 64.
113. 64. 133. 56.
133. 56. 161. 58.
161. 58. 205. 76.
BLOCK
200 9 20.
38. 63. 38. 63. 0.
48. 55. 48. 55. 4.
58. 52. 58. 52. 4.
68. 53. 68. 53. 4.
78. 57.01 78. 57.01 2.
94. 65.01. 94. 65.01 0.
120. 75. 120. 75. 4.
130. 82. 130. 82. 4.
135. 92. 140. 92. 0.

```


PARTIAL OUTPUT FOR FOURTH RUN -

SEARCHING ROUTINE WILL BE LIMITED TO AN AREA DEFINED BY 8 BOUNDARIES
OF WHICH THE FIRST 8 BOUNDARIES WILL DEFLECT SURFACES UPWARD

BOUNDARY NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)
1	0	15.00	29.00	24.00
2	29.00	24.00	51.00	26.00
3	51.00	26.00	78.00	56.00
4	78.00	56.00	94.00	65.00
5	94.00	65.00	113.00	64.00
6	113.00	64.00	133.00	56.00
7	133.00	56.00	161.00	58.00
8	161.00	58.00	205.00	76.00

A CRITICAL FAILURE SURFACE SEARCHING METHOD, USING A RANDOM
TECHNIQUE FOR GENERATING SLIDING BLOCK SURFACES, HAS BEEN
SPECIFIED.

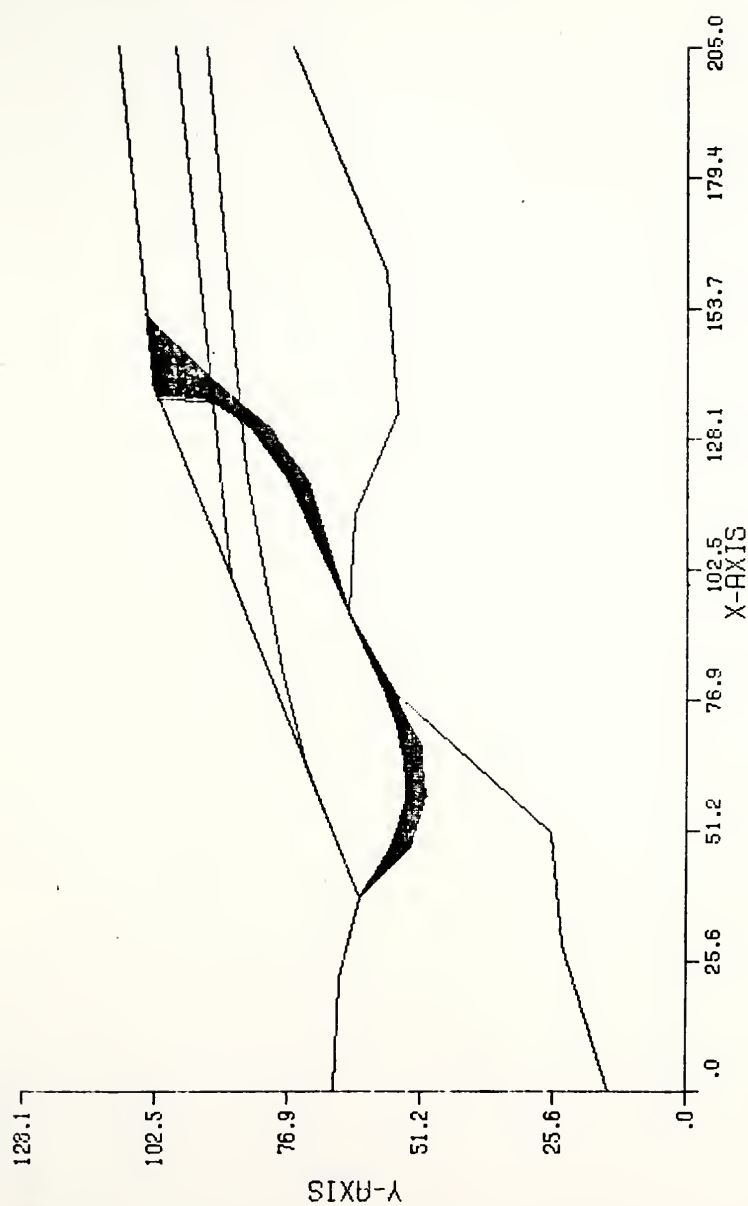
200 TRIAL SURFACES HAVE BEEN GENERATED.

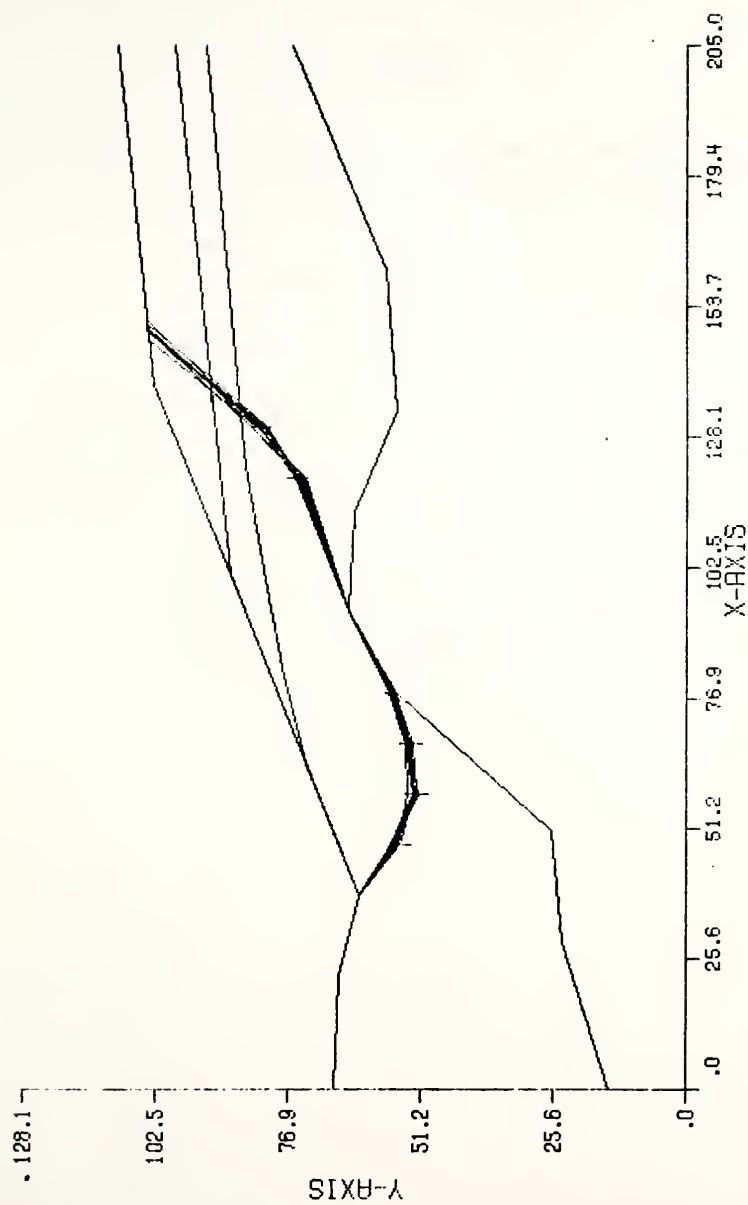
9 BOXES SPECIFIED FOR GENERATION OF CENTRAL BLOCK BASE

LENGTH OF LINE SEGMENTS FOR ACTIVE AND PASSIVE PORTIONS OF
SLIDING BLOCK IS 20.0

BOX NO.	X-LEFT (FT)	Y-LEFT (FT)	X-RIGHT (FT)	Y-RIGHT (FT)	WIDTH (FT)
1	38.00	63.00	38.00	63.00	0
2	48.00	55.00	48.00	55.00	4.00
3	58.00	52.00	58.00	52.00	4.00
4	68.00	53.00	68.00	53.00	4.00
5	78.00	57.01	78.00	57.01	2.00
6	94.00	65.01	94.00	65.01	0
7	120.00	75.00	120.00	75.00	4.00
8	130.00	82.00	130.00	82.00	4.00
9	135.00	92.00	140.00	92.00	0

Figure 1 is a scatter plot showing the relationship between the number of days from the start of the study to the first observation of a given species (Y-axis) and the number of days from the start of the study to the last observation of a given species (X-axis). The Y-axis ranges from 0.00 to 205.00, and the X-axis ranges from 0.00 to 205.00. Data points are labeled with species abbreviations: L (Lepidoptera), M (Mammalia), S (Sauria), I (Insecta), X (Xenarthra), and F (Fungi). The plot shows a positive correlation, with most species having their first and last observations within 100 days. Some species, like Lepidoptera (L), have observations extending up to 205 days.





UNITS

All units used for any one problem must be consistent. The printed output is limited to the following units for dimensioning.

Length	(FT)	feet
Unit Weight	(PCF)	pounds per cubic foot
Stress	(PSF)	pounds per square foot
Direction	(DEG)	degrees

Metric units or any set of consistent units can be used. It must be kept in mind, however, that the printed output will bear the units listed above. A consistent set of metric units for example would be

Length	(M)	meters
Unit Weight	(KG)	kilogram per cubic meter
Stress	(KG/SQM)	kilogram per square meter
Direction	(DEG)	degrees

PROBLEM SIZE LIMITATIONS

STABL as dimensioned in the program listing is capable of handling problems defined as follow.

Data	Maximum Number
profile boundaries (total)	100
*) piezometric surfaces (total)	10
points defining a single water surface	40
points defining specified trial failure surface	100
surface generation boundaries	20
uniformly distributed surcharge boundary loads	10
soil types (total)	20
anisotropic soil types	10
direction ranges of each anisotropic soil type	10
boxes for sliding block surfaces	10

The program can be adjusted to handle larger problems by changing dimension statements. The availability of the computing machine's memory core will take precedence with regard to how large a problem can be ultimately handled.

- *) The possibility of defining several piezometric surfaces has been added to the program. This can be used e.g. in cases with artesian water or a perched water table.

Card deck of computer program STABLContent List

STBL1:	STABL	main program	
	READER	subroutine	
	QUIT	"	
STBL2:	PROFIL	"	+ Entry SOIL
STBL3:	ANISO	"	
	WATER	"	
	LOADS	"	
STBL4:	EQUAKE	"	
	LIMITS	"	
	INTSCT	"	
	SURFAC	"	
STBL5:	RANDOM	"	+ Entry BLOCK
STBL6:	RANSUF	"	
STBL7:	BLKSUF	"	
	BLOCK2	"	
	SORT		
STBL8:	EXECUT	"	
	SLICES	"	
	WEIGHT	"	
STBL9:	SOILWT	"	
	FACTR	"	
	SCALER	"	
STBL10:	PLOTIN	"	
	PLTN	"	
	POSTN	"	

Example of Data set up for STABL

DDAFIL

1-275 STA 52+00 EFFECTIVE STRESS

UG-364(17)

23 11

0. 46. 10. 46. 4

10. 46. 17. 42. 4

17. 42. 26. 42. 4

26. 42. 34. 46. 4

34. 46. 56. 45. 4

56. 45. 90. 56. 1

90. 56. 145. 75. 2

145. 75. 156. 76. 2

156. 76. 240. 105. 1

240. 105. 250. 108. 1

250. 108. 320. 108. 1

156. 76. 320. 78. 2

90. 56. 320. 58. 1

56. 45. 216. 38. 4

216. 38. 320. 43. 4

0. 36. 20. 36. 5

20. 36. 136. 20. 5

136. 20. 216. 32. 5

216. 32. 320. 28. 5

0. 22. 136. 22. 4

0. 17. 31. 17. 1

31. 17. 136. 22. 1

136. 22. 320. 22. 1

501L

5

125. 125. 0. 35. 0. 0. 1

125. 125. 0. 33. 0. 0. 1

125. 125. 0. 35. 0. 0. 1

122. 122. 320. 20. 0. 0. 2

122. 122. 740. 16. 0. 0. 2

WATED

5 0.

5

0. 45. 56. 45.

126. 51. 216. 47.

320. 47.

7

0. 45. 56. 45.

126. 51. 136. 60.

150. 64. 250. 112.

320. 110.

BLCK2

50 2 50.

30. 30. 80. 26. 8.

140. 26. 280. 26. 6.

ends to interchange in STABLE to use program on an IBM computer

DIMENSION KEYW(17),ERROR(5),WAR(100)

REAL*8 MKEYW,KEYW

TOL=0.01

CALL PLOTS(WAR,400)

READ(5,100,END=19)MKEYW

IF(1/PROF.F0.1)GO TO 23

ENTRY INTSC2(X1,Y1,X2,Y2,X3,Y3,X4,Y4,X5,Y5,INTSC)

CALL NUMRED (1.5,4.0,0.1,FLOAT(TAL),0.0,-1)

CALL NUMRED (3.8,5.7,0.1,ESS(1),0.0,3)

CALL AXIS(0.0,0.6HX-AXIS,-6.8,0.0,SCALE,1.0,1.0,125)

CALL AXIS(0.0,0.6HY-AXIS,6.5,1.5708,0.0,SCALE,1.0,1.0,125)

CALL NUMRED(4.95,5.7,0.1,FS,0.0,3)

FUNCTION RANF(X)

INTEGER XN,SEED

DATA XN,SEED/16384,27497/

SEED=MOD(SEED*78125,XN)

RANF=FLOAT(SEED)/FLOAT(XN)

RETURN

END

STBL 250

STBL 251

STBL 252

STBL 292

STBL 310

STBL 336

STABG

Main

ISCT 228 Subr. INTSC2

DAND1893 Subr. RANDOM

DAND18A8

PLOT 764

PLOT 765

PLOT 567

Subr. PLOTIN

RANF 2

RANF 4

RANF 6

RANF 8

RANF 10

RANF 12

RANF 14

Random

Function

COVER DESIGN BY ALDO GIORGINI